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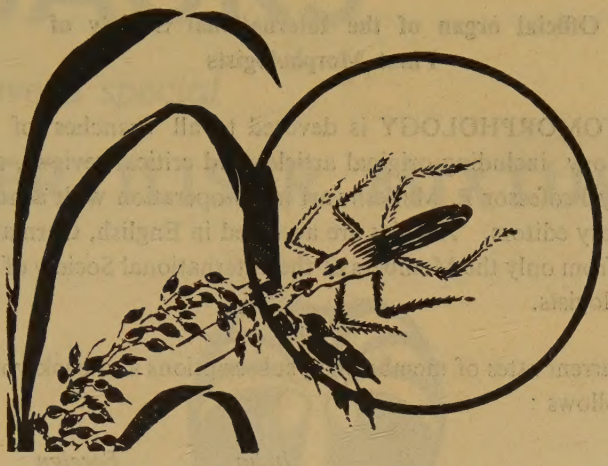

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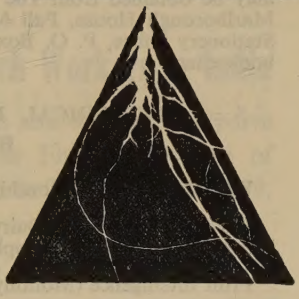

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THE "TROPICAL AGRICULTURIST" IS REGISTERED AS A NEWSPAPER IN CEYLON

EDITORIAL

Weed Control in Rice

PROFUSE weed growth which sometimes completely smothers the crop is one of the major causes of poor rice yields in many parts of Ceylon. However, as the density of weed growth varies even from field to field it is very difficult to assess the exact extent to which weeds depress rice yields each season.

At present weed supervision in rice fields is attempted mainly through preparatory tillage and impounding of water. A high degree of weed control can be achieved by this method if the weeds are buried by ploughing and kept submerged for a long period by impounding water. But field preparation over the greater extent of the rice acreage in Ceylon has to be hurriedly carried out within a short period that this method of weed suppression seldom yields satisfactory results, and weeds appear even ahead of the rice seedlings. In row-planted and row-seeded crops, however, weeds can be effectively controlled with the aid of the rotary weeds which crushes all weeds in-between the rows of rice seedlings. These cultural techniques which can be interpreted largely as measures of weed suppression are still practised on a restricted scale that alternative methods of weed control are needed for the large extents of broadcast fields.

So far the only effective method of weed control in broadcast rice has been the actual removal of weeds by hand. Though effective, hand weeding is both difficult and expensive. The main difficulty in hand weeding is the close resemblance of the pernicious weed seelings to rice. Many of them belong to the grass family and are practically indistinguishable from rice till they flower. Hence, picking them out in a broadcast rice field is extremely difficult. Harrowing the growing crop, though less effective than hand-weeding, is a satisfactory alternative where labour is scarce and expensive.

The real answer to the problem of weeds in rice appears to lie in the use of weed killers that will not cause any harm to the rice plant. Since World War II selective weedicides have begun to play an increasingly important role in crop production but a weedicide that could be safely applied in rice cultivation in the tropics was not available till very recently. Now that the final break-through has come it seems only a matter of time before weedicides become a regular feature in paddy cultivation in Ceylon. The only factor that appears to check the rapid spread of this method of weed control is the present high price of weedicides. It is, therefore, hoped that weedicides will shortly be available at a more reasonable price.

DISEASE HAZARDS IN POTATO CULTIVATION

I.—Late Blight caused by Phytophthora infestans (Mont) de Bary

By

D. V. W. Abeygunawardena & I. Balasooriya

(Agricultural Research Station, Rahangala)

INTRODUCTION

LATE Blight is undoubtedly the most serious disease of potato in humid and wet areas of the hill country. It attacks the foliage of potato plants and invades the tubers causing a wet rot. It has been amply demonstrated that spraying for blight pays in areas where the disease is an important factor (1,2.). The disease is endemic in Ceylon and epiphytotics may occur at any time during certain growing seasons. The weather is rather variable in the Nuwara Eliya area with cool nights, frequent rains and high relative humidity, conditions under which the disease can be serious. The source of the primary inoculum does not necessarily depend on infected tubers as potato, tomato and other solanaceous crops grow spontaneously the year round. The occurrence of epiphytotics of late blight in the hill country areas, is, therefore, attributed to the endemism of *Phytophthora infestans* and to the generally favourable local environment. In the Nuwara Eliya area there are many unsuspected micro climates apparently adequate for the year round existence of the pathogen.

The question of controlling late blight is an important requisite for the successful potato culture in the hill country areas. In addition to the control achieved by fungicidal spraying, it was considered necessary, that adjustments in cultural practices and the use of resistant varities are factors which may contribute to the prevention of the disease, more specially in the hands of peasant cultivators.

SYMPTOMS AND EFFECTS

Late blight appears on the leaves where it causes brown, dead spots or large dead areas until the leaves are killed. In moist conditions and with susceptible varieties the entire leaf may be killed

in 1-4 days. With the intervention of dry weather, progress of infection is retarded and blighted leaves soon curl and shrivel, while under moist conditions they decay rapidly. The disease results in blackening and wilting of entire tops followed by a wet rot involving the stems as well as the foliage. The lesions produce a delicate whitish or greyish fungus on the under surfaces of leaves. The effect of Late Blight on tubers may be primary or secondary. The early blighting of the foliage will reduce the size and number of tubers. The primary infection of tubers, on the contrary, causes a dry or wet rot according to the prevailing conditions.

It has been clearly demonstrated (2) that an increase of nearly 4 tons per acre of harvested tubers has been obtained in experimental plantings where the disease was effectively controlled. The loss of crop due to the disease can be enormous in severe blight weather and with highly susceptible varieties.

RESISTANCE OF POTATO TO LATE BLIGHT

THE genetics of resistance to Late Blight in potato has been clearly understood during the last few decades (3, 4, 5). There are basically two types of resistance, namely, field immunity or major gene resistance and field resistance or minor gene resistance. The former type of resistance is conferred by 4 major genes labelled by Black (5) as R1, R2, R3 and R4. Each gene was found to be inherited independently and conferred resistance to the common physiologic race of the pathogen as well as certain specialised races. Sixteen different genotypes including the recessive have been obtained from crosses involving the 4 major genes. On the contrary, the minor gene or field resistance appears to be equally effective against the races of the pathogen. This type of resistance is characterised by continuous variation and its inheritance is attributed to a polygenic system.

IDENTITY OF RACES OF P. INFESTANS

WITH the object of exploiting major gene resistance in potato culture, especially, as large scale cultivation is new to the country, an investigation was undertaken to ascertain the physiologic races of *P. infestans* present in the potential potato growing areas. Fifteen different genotypes obtained through the courtesy of Black (personal communication) consisting of the individual major genes or in combination and the recessive were used for the identification of the races of *P. infestans*. The different genotypes and the recessive were submitted to trial at Nuwara Eliya, Bopatalawa and Horton Plains.

Late Blight did not appear in the last named test area ; the results of the tests at Nuwara Eliya and Bopatalawa are collectively summarised in Table 1. In both test areas none of the genotypes were completely immune, those lacking lesions with active sporulation exhibited hypersensitivity. The races of *P. infestans* found to be most virulent in both test areas were 0, 1, 2, 4 and 1, 2. In the test at Bopatalawa the race 3, 4 was also present in a less virulent form ; the same race of the pathogen was identified in subsequent the tests at Nuwara Eliya. It has been shown (4) that specialisation of the fungus normally progresses by steps from one order to another towards a wider host range ; the mode of origin of new races being attributed either to physiological adaptation or mutation.

In view of the existing races of *P. infestans* and the possible appearance of new races, large-scale cultivation of these genotypes may be temporary. In Tanganyika, however, a genotype known to show hypersensitivity has been cultivated for several years without any signs of blight attack. (6).

TESTS ON VARIETAL RESISTANCE

Early attempts to determine the varietal resistance to late blight infection were made at the Agricultural Research Station, Rahangala. Different potato varieties were submitted to natural infection in the monsoon season when epiphytotics usually occur on a field scale. The varieties evaluated are grouped below, according to the level of resistance shown in the experiments.

(*a*) **Varieties with 100 per cent. foliage infection.** Up to Date, Craigs Defiance, Hybrid 9, Home Guard, Craigs Royal, Kerrs Pink, Arran Pilot, Arron Banner, King Edward, Majestic, Alpha, Arran Peak and British Queen. The variety British Queen succumbed with 100 per cent. leaf blight in 6 weeks whereas the other varieties required 8-10 weeks to reach the same grade of infection.

(*b*) **Varieties with 50 per cent. foliage infection.** Japanese No. 4, Japanese No. 6 and Meerster showed this rating in 12 weeks.

(*c*) **Varieties with no active infection.** Ulster Torch. This variety had hypersensitive spotting on foliage.

Later tests on resistance were conducted at Nuwara Eliya, where the prevailing cool nights, frequent rains and constant high relative humidity were conducive to severe infection. Each variety was evaluated for the degree of susceptibility to infection by the pathogen

and to the field resistance shown after infection. The potato varieties listed according to the degree of susceptibility to infection are given below.

(*a*) **Highly Susceptible Varieties.** Voran, Maritta, Alpha, Prof. Broekema, Poet, Profijt, King Edward, Tedria, Up to Date, Local Selection *S. tuberosum* sub species *andigenum* (8), Delus, Ashworth, Courtland, Saco, Harford, Placid, Pungo, Essex, Prisca, Gineke, Phulwa, Darjeeling Red Round, Indian Seedlings ON 2236 and ON 1360 and Ambassadeur. Of the varieties in this category King Eward, Tedria, Up to Date and Indian Seedling ON 1360 produced active sporulating lesions in less than 7 weeks whereas in other varieties sporulation was delayed to 8-9 weeks.

(*b*) **Moderately Susceptible Varieties.** On Rival, Virgil and Indian Seedling ON 45 sporulating lesions appeared after 9 weeks.

(*c*) **Resistant Varieties.** Dekama, Dutch Seedlings GB 5269-22, GB 5210-5-9 and GB 5244-8 produced hypersensitive type of spotting on the leaves.

Perhaps the most important consideration in determining resistance is the rapidity with which potato varieties succumb to infection under natural epiphytotic conditions. The potato varieties evaluated have been listed in Table 2 on the basis of resistance shown after attack by the pathogen.

The varieties Delus, Up to Date and King Edward though highly susceptible to late blight and exhibiting poor field resistance showed relatively good yield potential, a condition attributable to early tuberisation of these varieties. Gineke, Prof. Broekema and Profijt while being highly susceptible to infection exhibited a useful degree of field resistance enabling the crop to succumb gradually. These varieties, in contrast, to others of the same category, have the ability to tuberise relatively early. The variety Tedria is highly susceptible to initial infection and has poor field resistance. Unlike Gineke it succumbs to infection rapidly. Voran, Ambassadeur and the local selection *S. tuberosum* sub species *andigenum* are highly susceptible to infection but do not break down with disease rapidly, thus possessing a high degree of field resistance. The varieties Voran and Ambassadeur tuberise relatively early whereas the local selection exhibited a poor yield potential under blight conditions. The seedling GB 5269-22 and Dekama produced hypersensitive reaction and were the least affected by the disease. The loss of crop caused by late blight being negligible in these varieties they would be safe in the hands of peasant cultivators.

CLIMATIC FACTORS IN RELATION TO DISEASE DEVELOPMENT

Factors which define the growing seasons in each climatic zone in the hill country are rainfall, temperature, wind and frost. Both high humidity and rainfall play an important part in the development and spread of late blight. Rain provides the moisture necessary for the germination of sporangia on the leaves and also raises the humidity within the crop. Sporangia are produced liberally (7) in an atmosphere with more than 91 per cent. relative humidity and at a temperature range of 46°-59°F. The sporangia have been found to lose their viability in 1-2 hours exposure to dry air. It has been described (7) that free water or dew on the leaves is an essential requirement for sporangial germination. Direct sporangial germination occurs at 48°-79°F whereas indirect germination by zoospores require both free moisture and low temperatures 58°-59°F. Ideal humidity and temperature requirements both for indirect sporangial germination and rapid field spread of the disease are found during certain seasons in the hill country areas. It is, therefore, necessary that the growing seasons should be restricted with the view to escaping blight epiphytotics or raising crops with the minimum infection. The climagrams (Figs. 1 & 2) show the different growing seasons in respect of each climatic zone. In areas receiving predominantly the South-West Monsoon rains the crops which fully or partly escape blight are in the October and January sowing seasons. While the temperatures are satisfactory for economic tuberisation all the year round, blight epiphytotics would be specially serious in the monsoon rains from May to September. In parts of the hill country influenced by the North-East Monsoon the crops which fully or partly escape blight would be in the January, April and July sowing seasons. Accordingly the cropping seasons for escaping late blight epiphytotics could be outlined as follows for each climatic zone. In the climatic zone influenced by the North-East Monsoonal rains. (Fig. 1), viz., Bandarawela, Welimada, Ragalla, Maturata, etc., the recommended seasons for disease escape are—

(*a*) **January-April Season.** With a variety like Gineke which is susceptible to infection but possessing considerable field resistance, 1-4 protective fungicidal sprays would be necessary with the increase of rainfall and relative humidity towards the close of the season.

(*b*) **April-July Season.** During this season potato crops are grown in protected locations due to the strong and desiccating winds experienced. The humidity is relatively low and unfavourable for

blight development. Spraying is unnecessary in most areas except in regions where the local climate or microclimate necessitated fungicidal protection.

(*c*) **July-October Season.** With Gineke 1-4 sprays would be necessary particularly with the advance of the season when both atmospheric relative humidity and the rainfall increase, thereby causing conditions favourable for development of blight.

In the climatic zone, influenced by the South-West Monsoonal rains (Fig. 2), viz., Nuwara Eliya, Bopatalawa, Hatton, Kuda Oya, etc., the seasons recommended for blight escape are the following :—

(*a*) **October-January Season.** With Gineke, about 1-5 protective sprays are required mostly in the first half of the growing season when both rainfall and relative humidity are conducive to disease development.

(*b*) **January-April Season.** Protective spraying, about 1-6 spray applications, may be necessary both in the first half and towards the close of the season when the relative humidity and rainfall appear favourable for disease development.

DISCUSSION

Evidence is presented on the methods of field control of late blight by any one or combination of the following methods :—(*a*) fungicidal spraying, (*b*) the use of hypersensitive or resistant varieties, and (*c*) restriction of cropping seasons in each climatic zone to escape blight epiphytotics.

In view of the existence of a number of physiologic races of *P. infestans* and of the possibility of the appearance of new races the use of major gene resistance may be short lived. The evaluation of potato varieties on the basis of susceptibility to attack and the degree of resistance exhibited after infection, revealed that there are hypersensitive varieties and those incorporating both good field resistance and high yield potential which can be successfully cultivated under local conditions.

The analysis of climatic factors in relation to disease showed that the conditions prevailing in the hill country areas are for the most part suitable for disease development and spread. The climagrams

illustrate the cropping seasons in the major climatic zones with the object of escaping blight epiphytotics. While incorporating both inherent varietal resistance and fungicidal control the necessity for avoidance of disease by restricting growing seasons is emphasised.

SUMMARY

1. The physiologic races of *P. infestans* prevalent in the hill country areas have been identified.

2. A large number of potato varieties have been evaluated for both hypersensitive reaction and field resistance. Their relative yield potential in blight conditions is discussed.

3. Climagrams have been presented illustrating the cropping seasons with a view to escape blight epiphytotics.

ACKNOWLEDGMENT

THE authors are thankful to Mr. D. Gunawardena for assistance in some of the experimental work.

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TABLE I

Races of *P. Infestans* identified in the hill country

Genotype	*Type of Leaf Lesion*		*Physiologic race present*
	Sporulated	*Hypersensitive*	
r	+	—	0
R_1	+	—	1
R_2	+	—	2
R_3	—	+	—
R_4	+	—	4
R_1R_2	+	—	1,2
R_1R_3	—	+	—
R_1R_4	—	+	—
R_2R_3	—	+	—
R_2R_4	—	+	—
R_3R_4	+	—	3,4*
$R_1R_2R_3$	—	+	—
$R_1R_2R_4$	—	+	—
$R_1R_3R_4$	—	+	—
$R_2R_3R_4$	—	+	—
$R_1R_2R_3R_4$	—	+	—

* Only identified at Bopatalawa.

\+ Infection present.

— Infection absent.

TABLE II

Relative Yield and Resistance of Potato Varieties after infection by *P. Infestans*

Poor Resistance		*Moderate Resistance*		*Good Resistance*		*Hypersensitive*	
Variety	*Mean Yield per plant in ozs.*	*Variety*	*Mean Yield per plant in ozs.*	*Variety*	*Mean Yield per plant in ozs.*	*Variety*	*Mean Yield per plant in ozs.*
Delus ..	10·51	Gineke ..	10·62	Ambassaduer ..	7·41	GB. 5269–22 ..	14·51
Up to Date ..	9·01	Prof. Broekema..	10·30	Voran ..	7·09	Dekama ..	10·61
King Edward ..	7·01	Profijt ..	9·04	Alpha ..	4·90	G.B. 5210–5–9 ..	8·21
Prisca	6·40	Maritta ..	7·09	Rival ..	3·63	GB. 5244–8 ..	7·55
Tedria ..	5·57	Pungo ..	5·87	*S. tuberosum* sub species *andigenum* (local selection)	2·72		
Placid ..	4·83	ON 45 ..	5·76				
Ashworth ..	4·45	Saco ..	5·14				
Courtland ..	4·37	Essex ..	4·70				
Virgil ..	3·52	ON 1360 ..	4·66				
Darjeeling ..		Harford ..	2·42				
Red Round ..	3·24	ON 2236 ..	2·16				
Poet ..	1·97	Phulwa ..	2·08				

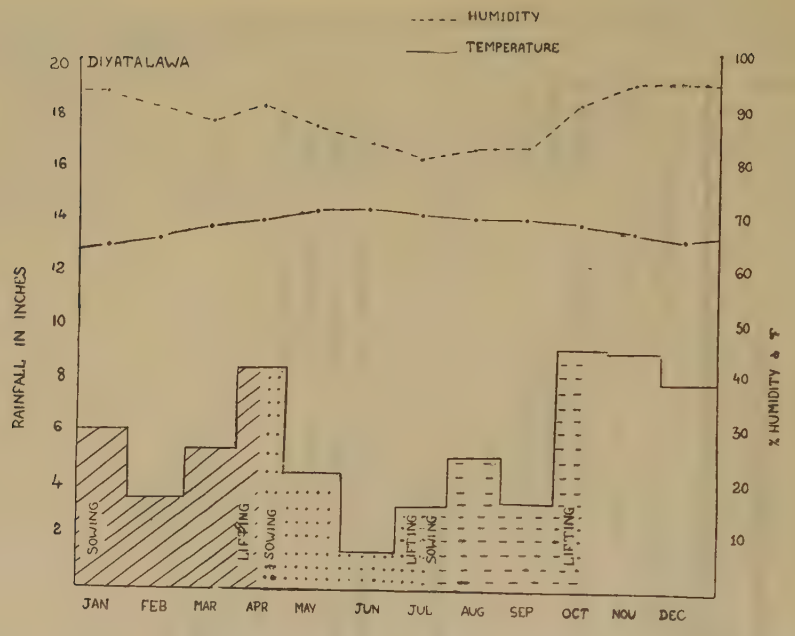

Figure 1.—Long-term average monthly rainfall, mean temperature and mean relative humidity in relation to potato cropping seasons for escaping late blight epiphytotics in the climatic zone influenced by the North-East Monsoon.

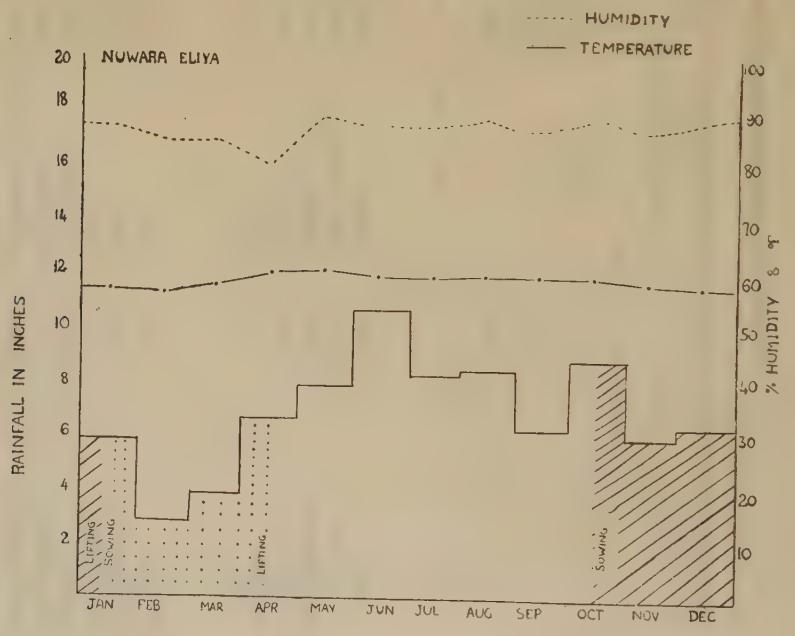

Figure 2.—Long-term average monthly rainfall, mean temperature and mean relative humidity in relation to potato cropping seasons for escaping late blight epiphytotics in the climatic zone influenced by the South-West Monsoon.

DISEASE HAZARDS IN POTATO CULTIVATION

II.—Brown Rot or Bacterial Wilt caused by Pseudomonas Solanacearum.

By

D. V. W. Abeygunawardena & A. A. P. Siriwardena,

(Agricultural Research Station, Rahangala)

INTRODUCTION

BROWN rot or bacterial wilt caused by *Pseudomonas solanacearum* is the most disastrous of all diseases affecting the potato crop in Ceylon. The first systematic survey of the disease was made in 1960 (1). This survey revealed that the disease is more or less the limiting factor in the extension of the crop into existing cultivators' holdings at elevations below 5,000 feet. In the absence of direct methods of combating this disease the importance of obtaining resistant potato varieties was recognised. Most work done in this connection in other countries involved the testing of common varieties and hybrid lines but none of these have shown high resistance or immunity. An attempt has been made herein to analyse the factors which would help in raising successfully both seed and commercial potato crops in Ceylon with a view to combat and avoid the disease.

SYMPTOMS OF DISEASE

The above ground symptoms characteristic of the disease are wilting, stunting and yellowing of the foliage. The first symptom invariably seen on a warm day is the drooping of tips of one or more lower leaves but this condition may be mistaken for shortage of soil water. The affected leaves may recover their turgidity towards evening but wilting will extend further the following day. A slight yellowing of the lower leaves becomes evident when the leaflets begin to droop ; sometimes only one branch on a single potato hill may show symptoms of wilt. In other cases, however, foliage of an entire hill may quickly wilt. (Plate I). Potato tubers from diseased plants may or may not show external symptoms. Brownish discolorations can sometimes be seen through the skin indicating that the disease is well advanced.

Examination of infected tubers usually reveals a distinct brown rot localised in the vascular rings. If a disease tuber is cut a slight pressure will force the typical greyish white bacterial slime out of the vascular ring. (Plate II). Infected tubers left in the ground continue to decay especially in wet weather. The secondary organisms gain entry and cause the breakdown of the tuber into a slimy mass surrounded by a thin layer of outer tissue.

The Pathogen. Rapid multiplication of *P. solanacerum* occurs at relatively high temperatures ; it shows resistance to relatively low temperatures (3). The bacterium is inactivated at pH below 4.0 (2) and rapidly multiplies under alkaline conditions. High soil moisture level resulting from high water table or heavy rainfall usually favour development of bacterial wilt. The bacterium is known to be aerobic and flooding soil as practised in paddy cultivation has harmful effects on its survival. This accounts for the lesser incidence of disease recorded in potato crops raised in rotation with paddy (1).

Investigation on Resistance of Potato Varieties. Reports on the relative susceptibility of potato varieties to this disease are numerous and conflicting. In extensive replicated field experiments potato varieties were planted in heavily infested soil at the Agricultural Research Station, Rahangala. In these experiments the following varieties were rated as susceptible with more than 75 per cent. of plants affected with bacterial wilt. In these tests the percentage of plants wilted was not the only criterion adopted in evaluating resistance. The age of wilting and tuber infection were also considered useful factors. The varieties are Sebago, Up to Date, Green Mountain, Katahdin, Great Scott, Voran, Gineke, Majestic, Arran Banner, Huron 1, British Queen, Phulwa, Hokkai 17, Pungo, Ulster Torch, Rival, King Edward, Dekama, Profijt, Essex, Tedria, Indian seedlings ON 1360 and ON 2236, Kentang, Wulong, Saco, Ambassadeur, Virgil, Courtland, Placid, Poet, Alpha, Cherokee, Noordeling, Arka, Dutch Seedlings GB 5269-22 and GB 5210-5-9, Libertas, Maritta, Pimpernal, Eigenheimer and the local variety *S. tuberosum* sub species *andigenum.* Five potato selections known to show some resistance to bacterial wilt in U. S. A. namely Prisca, 2117-117, 2407-12, 2410-78 and 56C-3 obtained through the courtesy of Prof. Neilson of North Carolina State College were also included in tests for resistance. Figure 1 shows progressive wilting of relatively resistant variety Prisca and a highly susceptible variety Dekama when tested in heavily infested soil. The variety Prisca exhibited fair resistance to bacterial wilt, 72 per cent. of plants wilting as against 95 per cent. of the variety Dekama.

CONTROL

Since the pathogen can be disseminated in seed potato tubers emphasis should be given to the use of disease free seed. The main object of such a recommendation is to prevent the introduction of the disease into fields where it is not present. Furthermore, the severity of infection is greatly reduced when plantings are made with disease free seed in fields where infestation is mild or uneven. Planting of disease free seed in infested soil, however, will not necessarily obviate the danger of serious crop losses. The use of disease free seed is of paramount importance in countries where seed potatoes are grown in infested soil. Rigid seed potato selection would therefore be an important means of reducing losses caused by bacterial wilt. Sterilization of the cutting knife with boiling water or by passing through a flame or dipping in mercuric chloride solution when there is a possibility of transmitting the bacterium from infected to healthy tubers is recommended. The control obtained by rotation with a non-susceptible crop has been attributed to starving out the organisms from infected soil.

ACKNOWLEDGMENT

The authors are thankful to Mr. D. Gunawardena for assisting in these investigations.

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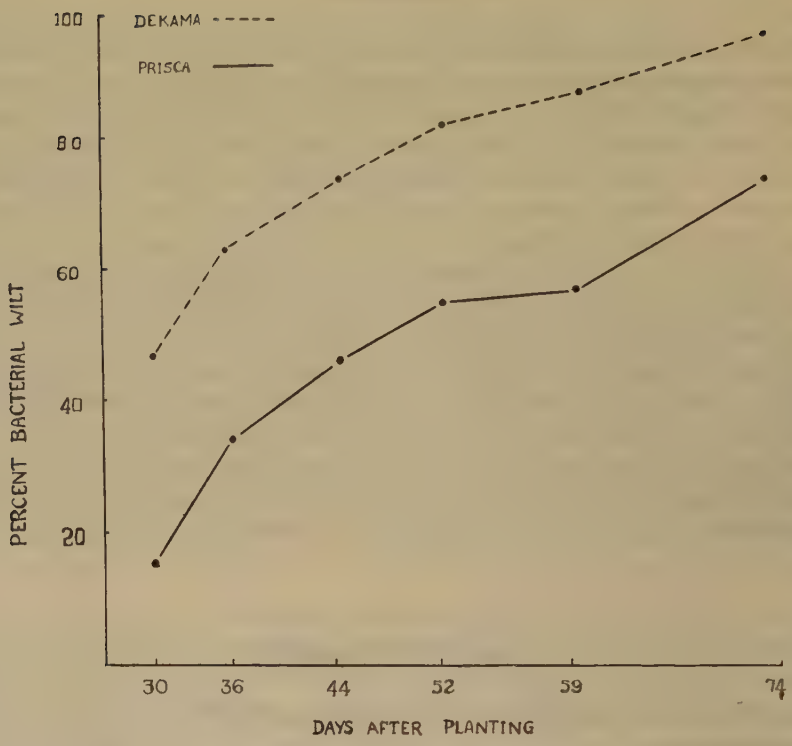

Fig. 1.—Relative susceptibility of the potato varieties Dekama and Prisca to bacterial wilt caused by *P. solanacearum*.

Plate I.—Potato plants affected with bacterial wilt caused by *P. solanacearum*.

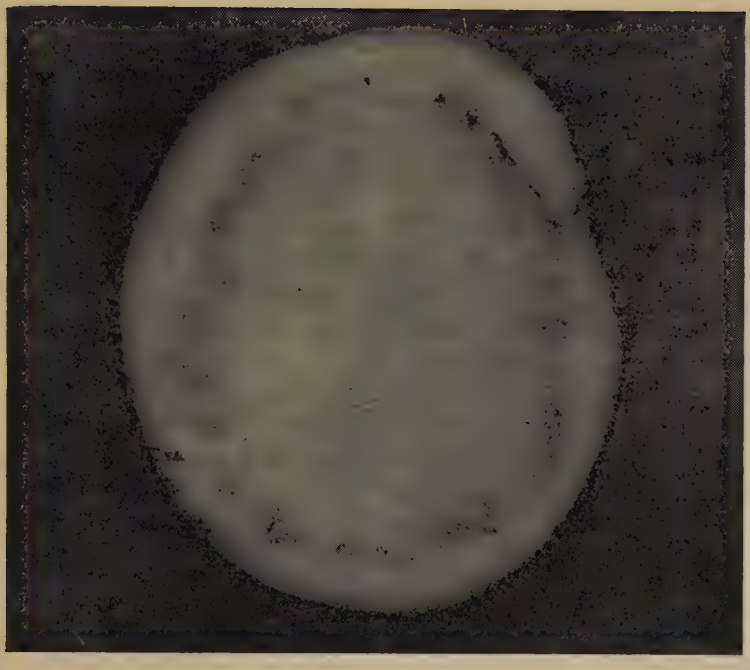

Plate II.—Cross section of an infected potato tuber showing discoloration of the vascular region and bacterial ooze of *P. solanacearum*.

A comparison of some Popular Mathematical Models used for the determination of the Physical Production Function in respect of Univariate Fertilizer Responses

By

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THE determination of economic fertilizer dosages is necessarily the ultimate goal in any fertilizer experimental programme on agricultural crops; and rightly so the agricultural scientist is now increasingly conscious of the importance of the economics of fertilizer use. However as the major portion of the techniques involved in the evaluation of the economic dosages of fertilizers—specially the determination of the physical production function relating fertilizer inputs to yield—falls within the domain of the Statistician or the Agricultural Economist, it is felt that any hints of guidance in such techniques will be welcome by most workers engaged in this field of research. In fact, even if the services of a Statistician were available, such information may be useful in that it will enable the Research worker to satisfy himself independently that the mathematical equation fitted by the Statistician does not run contrary to scientific principles.

This paper is devoted to a comparison of some popular mathematical models used for fitting curves on univariate fertilizer responses (namely, responses to different levels of a single nutrient or of a predetermined fertilizer mixture), with a view to determining a more universally applicable model. It also deals with a background review of some basic considerations regarding fertilizer response patterns as it is felt that such a prelude will be useful to a better appreciation of the above comparisons.

1. A REVIEW OF SOME POPULAR NOTIONS REGARDING FERTILIZER RESPONSE PATTERNS

(a) *The generalized fertilizer response curve*

Ever since the classical work of Mitscherlich (1909) on fertilizer responses, several investigators, on the basis of experiments with the

effects on yields of varying fertilizer inputs, have been led to conclude that the production function relating fertilizer inputs to yield is intrinsically an 'S' shaped curve. Jacob & Uexkiill (1960) in describing this trend observe that "very small dressings of fertilizers have mostly no effect at all or at best an unsatisfactory effect which does not justify the expenditure. It appears as though the amount of fertilizer must exceed a 'threshold value' for the result to become visible. The yield curve based on increasing quantities of fertilizers has therefore an S-shaped course".

Explaining this same trend, Lamer (1957) observes that "the production function relating fertilizers and yields depend upon the transformation of plant nutrients in fertilizers into plant food by the plant itself. If all other natural factors are maintained as constant, and attention is concentrated only on the effect of mineral nutrition, then it is noticed that the metabolic process uses, in each stage of plant growth, different proportions of the plant nutrients added to the soil in fertilizers. There is a small response on first addition because the soil retains more nutrients than the plant absorbs; after the addition of a 'minimum effective dose', a quick and large response follows in the plant; this response, however, slows down as the metabolism reaches the saturation point; beyond this point the additions of mineral nutrients have an irritating effect on the plant's plasm and can actually result in negative response in output".

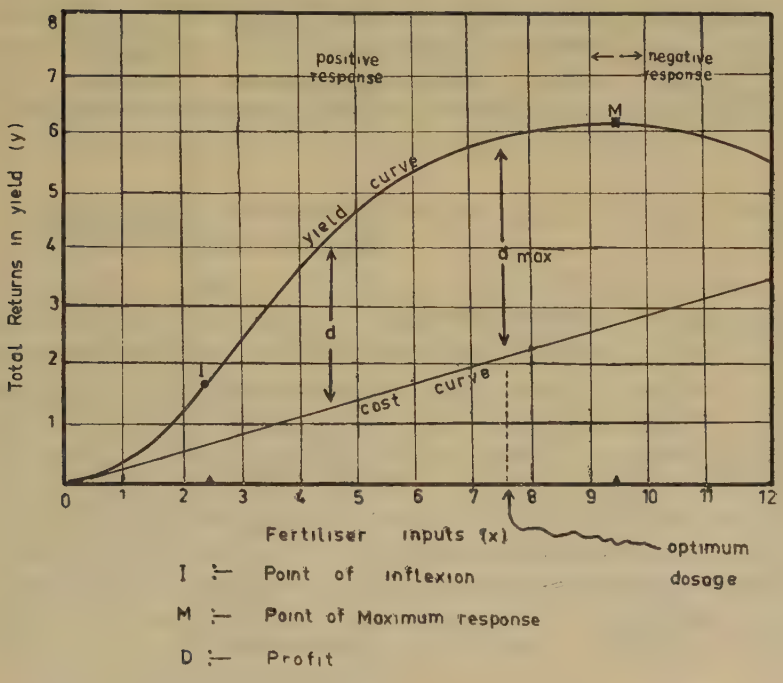
Fig. 1 gives a typical S-shaped fertilizer response curve where the soil originally (i.e. at zero level of fertilizer) can be considered almost completely void of nutrients. Near about the zero level, the response is negligible; as the dosage is increased, there is a very marked response at first giving indications of increasing returns; with further dosages (once the point of inflexion I is passed), the response falls away on a diminishing returns basis to reach a maximum at M; and with very high dosages, the response is negative.

(*b*) *Non-applicability of a standard equation in practice.*

Due to the limited range of fertilizer inputs that one normally tries out in field trials and the wide variations of the plant—soil—climatic complex in which such trials are conducted, the response curve in practice does not exhibit anything called a standard pattern and therefore, for all practical purposes, the term "standard response equation" may be a misnomer. Lamer (1957) refers to this when he states that "the relationship between fertilizer inputs and crop yields in actual soil conditions can sometimes be described by a Sigmoid

Fig (1)

S - shaped Fertiliser Response Curve

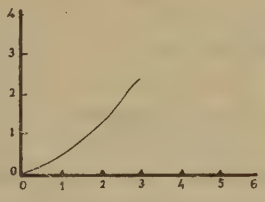
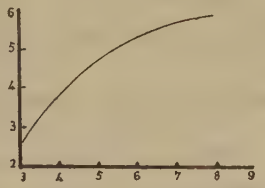
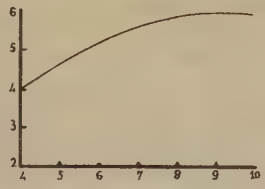
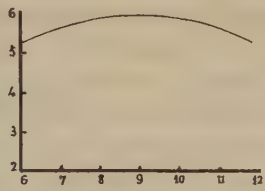


curve, whereas at other times there is an immediate diminution of additional yields. It is necessary to determine the productivity curve in each specific case, because different conditions, species and varieties of crops, and types of fertilizers result in different responses".

If we refer back to the generalised fertilizer response curve shown in Fig. 1, it is conceivable that, in a particular experiment, the observations may fall on different ranges of the fertilizer axis depending on the original nutrient status of the soil, the efficiency of the fertilizer used, and a host of other considerations. For instance, the ranges may be 0—3, or 3—8, or 4—10, or 6—12. Each range may call for different treatment from the point of view of fitting response curves. The pattern of response within each of these ranges as extracted from the relevant section of the general curve (Fig. 1) and also the type of empirical model that may reasonably explain each such pattern, are summarised in Chart 1, which is self explanatory.

Chart I

Fertiliser Response Patterns

Range of Fertiliser (Ref. Fig. I)	Relevant Pattern of yield response	Trends of response	Suitable Empirical model
0 – 3		(1) Increasing returns	Logistic Curve
3 – 8		(1) Diminishing returns (2) No indications of depression	Cobb Douglas' or Mitscherlich's or Polynomial
4 – 10		(1) Diminishing returns (2) Slight depression	Polynomial
6 – 12		(1) Diminishing returns (2) Symmetrical before & after maximum	Polynomial parabolic)

The first level in the range gives the original fertiliser level in the soil

From the above, it is reasonable to suggest that the idea of fitting a standard equation for fertilizer responses observed under field conditions—if such an equation exists at all—has no sound factual basis. On the other hand, such indiscriminate treatment may introduce serious divergences between observed and predicted values in some portions of the curve—a situation which is very unsatisfactory in problems of estimating optimum fertilizer dosages. Every situation, therefore generally calls for independent treatment based on its own trends as well as other scientific considerations.

(c) *Truncated nature of response curves met with in the estimation of optimum fertilizer dosages.*

While so many types of curves are applicable in determining the response patterns, the data from field experiments are such that the increasing returns part of the generalised response curve is seldom encountered unless the soil is extremely poor in nutrient content. Russel (1932) confirms this in his observation that " experiments do not always give sigmoid curves, but a simple shape showing a continuous fall in effect of the nutrient, the first increment producing the largest effect and subsequent increments less and less effect till finally no additional gain and sometimes even disadvantage ensues. Whether the sigmoid or the continuously falling curve more nearly represents the normal effect of nutrients on plant growth is not known. It is possible that the curve is usually sigmoid, but the point of inflexion is so near the origin that it is commonly missed ".

However, even if there are situations in which the increasing returns portion of the curve is clearly indicated, it will be appreciated that due to limitations imposed by the experimental range of observations, such a curve very seldom extends far beyond the point of inflexion of the curve—that is the point of commencement of the diminishing returns phase. And in such a situation, the question of estimating optimum fertilizer dosages does not arise unless one is prepared to tolerate a very lengthy and doubtful extrapolation.

Lamer (1957) probably sums up the above contentions when he states that " Fertilizer experts are not interested in the part of the curve below the point of inflexion ".

Therefore our problem of fitting response curves as a preliminary to estimating optimum fertilizer dosages, becomes more simplified in practice—being restricted to the regular concave (to the abscissa) type of curves following the law of diminishing returns or the " increasing—decreasing " curves as they are usually termed. In fact what

we observe in practice may be only a truncated form of the S-shaped response curve—that is with the increasing returns portion absent or obscured or of no interest.

(*d*) *Variation of "Increasing—Decreasing" response curves.*

Even within the simplified increasing—decreasing pattern mentioned above, response curves can exhibit wide variations. At least four distinct types can be reasonably expected within the experimental range and these in fact may be characteristic of the soil-plant-climatic set-up under consideration.

Fig. 2 shows the "increasing decreasing" curves referred to above. The dotted extensions to the common continuous line show some distinct variations within this family of curves to be expected under field conditions. All four curves are the diminishing returns type. In (*a*) the rate of increase tends to zero but never seems to reach zero. A continuous positive response is expected, however, infinitsemal it may be. In (*b*) the rate of increase reaches zero and the curve proceeds asymptotically. Here again no depression is anticipated. In (*c*) the rate of increase falls below zero and therefore gives rise to a depression ; but the rate of fall of the gradient occurs at a decreasing rate. In (*d*) the increasing—decreasing pattern is similar to (*c*) ; but the rate of fall of the gradient is a constant. It must however, be noted, that the continuous line drawn common to all four types, is so done purely for convenience. This early section too may vary according to the above four types ; or it may even be that the portion showing the positive response follows a certain law and the portion showing the depression follows yet another law. But such refinements are beyond the scope of our present knowledge and certainly beyond the scope of the present paper where we are only interested in a single curve to fit univariate fertilizer responses.

2. RECOGNISED EMPIRICAL MODELS FOR "INCREASING—DECREASING" RESPONSE CURVES

Before suggesting mathematical models for use in fitting the above type of response curves, it will be important to understand the context in which such models are suggested. Mitscherlich and a few others when they suggested mathematical models for response curves were mainly interested in determining "constant efficiency factors", implying universality of application to some degree or other. However in problems of estimating optimum fertilizer dosages, one thinks of

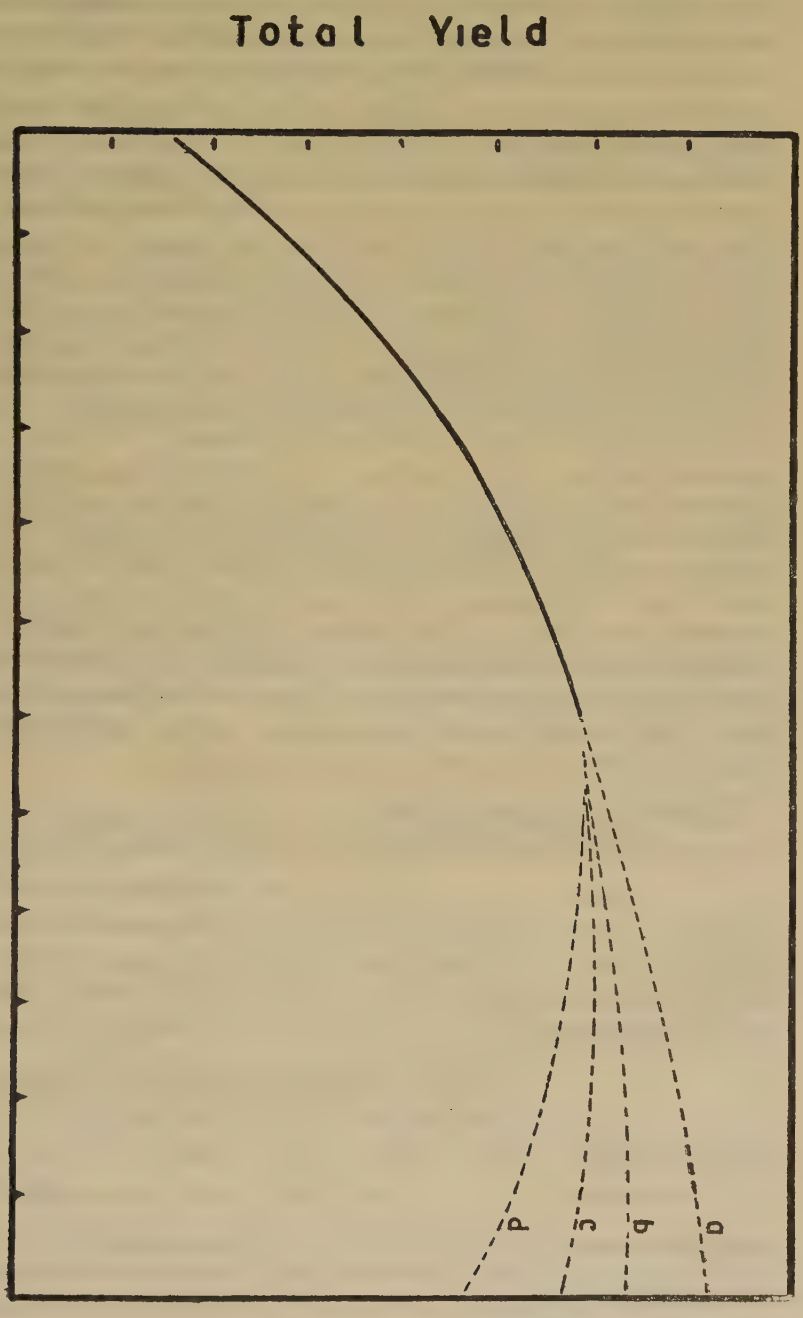


Fig. 2

the response curve primarily as a convenient method of interpolation—probably with some provision also for a little extrapolation—implying thereby that no attempt whatsoever is made to establish its universal applicability. In fact Crowther and Yates (1941) when they employed an adaptation of Mitscherlich's model, did so on this same principle.

On this basis, several algebraic forms are available and have been successfully used in fitting curves to "increasing—decreasing" fertilizer responses. These include several complex higher degree curves which have given excellent fits. However the latter, although they perform well within the observed range, are generally not recommended because apart from the computational difficulties, they have, according to Anderson (1957), undesirable properties for small and large values of the level of fertilizer. He also points out that "although this undesirable feature may not be too important so long as it performs satisfactorily within the relevent range, it is important in estimating optimum fertilizer application". If then we avoid complex higher degree curves, we observe that published work indicate four specific types of functions that are popularly used in fitting fertilizer response curves. Different adaptations of these are sometimes used—for example, the adapted forms of Mitscherlich's model used by Spillman (1933) and Crowther & Yates (1941). But the main principles are those covered by these four models. Anderson (1957) in fact has used these four models in a study with respect to some special aspects of fertilizer responses. It may be noted, in passing, that Cobb-Douglas' model given herein is the Allometric equation used very often in studies on organic growth.

The models are given below :—

Model	*Equation*
(1) Mitscherlich's Model	$\hat{Y} = A - be^{-ax}$ or $\hat{Y} = A - br^{x}$ $(\log_e r = -a)$ or $\log (A - \hat{Y}) = \log b + X \log r$ (linear form)
(2) Allometric Model (Cobb-Douglas')	$Y = a + \beta \times \alpha$ or $\log (Y - a) = \log\beta + \alpha \log x$ (linear from)
(3) Quadratic Model ..	$Y = a + bx - cx^2$
(4) Square Root Model ..	$Y = a - bx + c\sqrt{x}$

$\hat{Y}$ is the expected yield ; A is the maximum yield under ideal fertilizer conditions to be estimated from the data ; x is the level of fertilizer ; a, b & c in the quadratic and square root models, b, r & a of the Mitscherlich's model, and α & β of the Allometric model, are parameters to be estimated by the method of least squares ; a in the Allometric model is the average yield at zero level of fertilizer ; e stands for epsilon = 2.71828.

The quadratic and the square root models are polynomial types which do not presuppose any fixed theory as such. On the other hand, the Mitscherlich's and Cobb-Douglas' models—first an asymptotic type and the second an ever-increasing type—both imply a distinct expectation with respect to the pattern of fertilizer response. The latter equations in their simplified linear forms may be defined as follows :—

(*a*) Mitscherlich's equation :—

The logarithm of the decrement in yield from the maximum yield is linearly (negatively) correlated with the fertilizer level.

(*b*) Cobb-Douglas' equation :—

The logarithm of the increment in yield over the yield at zero level of fertilizer is linearly (positively) correlated with the logarithm of the fertilizer level.

3. A COMPARISON OF THE EMPIRICAL MODELS

(*a*) *Mathematical considerations.*

In studies on dynamics of production with respect to any effective "input" (yield versus fertilizer in this instance), Econometricians conventionally direct their attention on three specific aspects of the production curve—namely ;

(1) Curve of total product (primary curve).

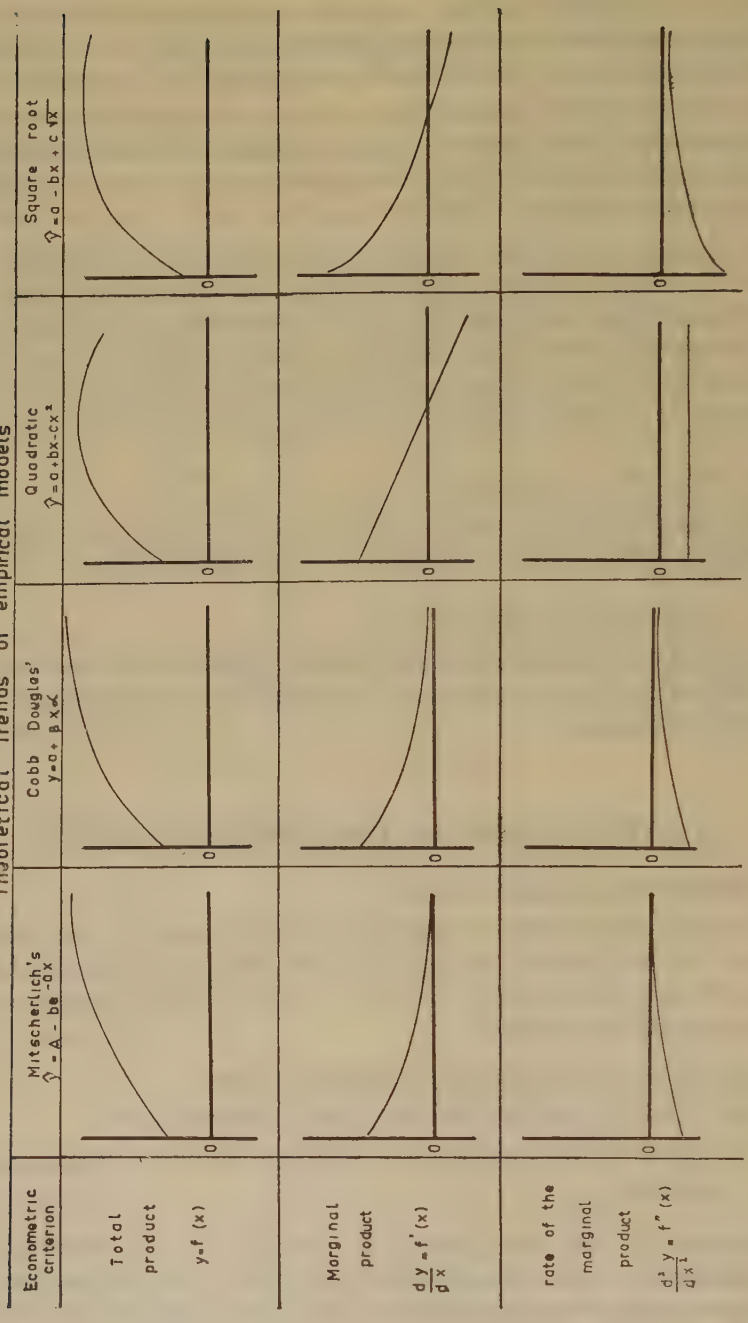
(2) Curve of marginal product (first derived curve).

(3) Curve of the rate of the marginal product (second derived curve).

The curve of the total product (y), in the present context, is the total yield curve with respect to the increasing levels of fertilizer (x). The curve of the marginal product is the curve of the gradient (dy/dx) of the yield curve, and shows the potential productive capacity of additional fertilizers. The rate of the marginal product is given by

Chart 11

Theoretical Trends of empirical models


Econometric criterion
Mitscherlich's $\hat{y} = A - be^{-ax}$
Cobb Douglas' $y = \alpha + \beta x^{\delta}$
Quadratic $\hat{y} = a + bx - cx^2$
Square root $\hat{y} = a - bx + c\sqrt{x}$
Total product $y = f(x)$
Marginal product $\frac{dy}{dx} = f'(x)$
rate of the marginal product $\frac{d^2y}{dx^2} = f''(x)$
0

the curve of the gradient of the gradient (d^2y/dx^2) of the yield curve and shows the tempo of the potential productive capacity of additional fertilizers.

The four mathematical models suggested earlier will be studied herein through these three specific criteria and their trends will first be examined on the basis of mathematical considerations.

Chart II, gives the general trends of the primary and the first and second derived curves (namely of y, dy/dx and d^2y/dx^2) with respect to each of the four models. These, as explained above, correspond to the curves of total product, marginal product and the rate of marginal product respectively.

The curves (though not drawn to scale) indicate the following broad patterns in respect of each of the three econometric criteria.

(1) Total product curve (y).

All equations show a positive response at the outset. But the Mitscherlich's model reaches a definite maximum and continues at that level ; Cobb-Douglas' model tends to, although it does not really reach a finite maximum ; and in the polynomial models—quadratic and square root—the response reaches a certain maximum and is then followed by a negative response.

(2) Marginal product curve (dy/dx).

From the point of view of the marginal product, all four models show diminishing returns by their downward trends. However, the Mitscherlich's and Cobb-Douglas' models set a limit of zero to the marginal product (the latter does not reach zero), whereas the polynomial models can cater to a negative marginal product too.

(3) Rate of marginal product (d^2y/dx^2).

The rate of the marginal product is negative in all the curves and this is necessarily implied in all forms of responses following the law of diminishing returns. The rate of this decrease of the marginal product itself decreases in the case of Mitscherlich's, Cobb-Douglas' and the square root models—this again being in keeping with most forms of biological responses. However the quadratic model is different, in that its rate of the marginal product is a constant.

(*b*) *Theoretical trends of models vis a vis trends of fertilizer responses.*

The efficiency of a mathematical model used to determine the law behind a given set of observed data in respect of some problem, has

to be guaged by the flexibility of the model—that is its adaptability to the whole range of variation expected in the problem. Therefore the theoretical background of the trends set out above in rspect of the four models, has to be examined in the light of certain reasonably established basic trends of "increasing—decreasing" fertilizer responses, which may be summarised as follows :—

(1) A positive response in the total product giving rise to a maximum later. Still later a negative response may or may not be observed.

(2) Decreasing positive marginal returns tending to zero. This may or may not be followed by negative marginal returns.

(3) Decreasing rate of fall away of marginal returns in most cases.

From the above it follows that (1) the polynomial models are superior to the other models in that the former can accommodate even depressing yields, and (2) from the point of view of the pattern of the marginal product, Mitscherlich's, Cobb-Douglas' and the square root models are superior to the quadratic model, because the latter suffers from the restriction of a constant rate of fall away of the marginal product.

Therefore one may reasonably conclude that, on a broad basis, the square root model is the most flexible type. However it is not contended that in a specific set of circumstances, any one of the other models would fit better and may even be more meaningful.

(*c*) *Comparisons on the basis of applications on experimental data.*

The above four models have been fitted on fertilizer response data based on four or more levels of nutrient application in respect of certain experiments conducted at the Coconut Research Institute of Ceylon. The data selected were only those that showed statistical significance in the Analysis of Variance.

The Mitscherlich's and Cobb-Douglas' models have been fitted on the basis of linear equations in respect of these models given earlier, transforming one or both variables as the case may be. In the case of Mitscherlich's model, the maximum response (A) has been estimated by Stevens' (1951) method of successive approximation reported by Anderson (1957). The other two equations have been fitted by the usual method of Multiple Regression.

A comparative index of the goodness of fit in respect of each model is calculated by

$$R \text{ (or } r) = \sqrt{\frac{\text{Sums of squares due to regression}}{\text{Total sums of squares of y}}}$$

Table I gives (1) the source of data (2) the variety of plant (3) the nutrient applied (4) number of levels including zero level and (5) index of the goodness of fit R or r.

The Mitscherlich's and Cobb-Douglas' models have not been fitted on data which showed any depression in yield at higher levels of fertilizer—being obviously unsuitable.

The observed and expected yields are not given due to lack of space.

The comparative merits of the four models explained earlier on the basis of mathematical considerations are amply confirmed by these applied results.

In general, polynomial models are better than Mitscherlich's and Cobb-Douglas' models ; and the square root model is more often than not superior to the quadratic model. Further the fact that in some specific cases, any one of the four models may suit better is also confirmed. It may also be noted that even in those few instances where the quadratic model is superior to the square root model, the extent of the superiority is not so large as to discourage one from recommending the square root model as a generally applicable model for " increasing—decreasing " curves.

DISCUSSION

The selection of a suitable mathematical model for fitting fertilizer response curves, calls for considerable judgement both from the point of view of the mathematical trends of the models available as alternatives as well as the trends observed in the data and also expected from scientific and other *ad hoc* considerations.

However, in practice, the need for that much of attention, does not seem to be seriously felt. Some work on the basis that " the proof of the pudding is in the eating of it ", and therefore select the model that gives the least residual error ; others stolidly lay their faith on a model with some popular law behind it—such as the Mitcherlich's—and attribute any deviations therefrom, however regular they may be, to experimental errors ; quite a few also prefer to use the common quadratic model in all instances regardless of its implications.

TABLE I

A Comparison of Mathematical Models on the Basis of Application on Experimental Data

Source of Data	*Variety*	*Nutrient*	*No. of Levels*	R (or r) = $\sqrt{\frac{\text{S. S. Due to Regression}}{\text{S. S. Due to } y}}$			
				Mitsche Rlich	*Cobb-Doug.*	*Quadra-Tic.*	*Square Root*
C 173 First Harvest ..	P. C.	K	4	0.9964	0.9816	0.9999	0.9961
C 194 First Harvest ..	P. C.	K	4	0.9892	0.9630	0.9774	0.9996
C 159 First Harvest ..	P. C.	P	4	0.9487	0.8090	0.9578	0.9861
C 189 First Harvest ..	P. C.	N	4	0.9734	0.9925	0.9887	0.9986
C 189 Thinings ..	P. C.	N	4	0.9849	0.9838	0.9858	0.9996
C 180 Second Harvest	P. C.	N	4	0.9989	0.9999	0.9985	0.9999
C 194 First Harvest ..	P. C.	P	4	0.9850	0.9999	0.9917	0.9999
C 173 First Harvest ..	P. C.	N	4	0.9825	0.9593	0.9999	0.9928
C 180 First Harvest ..	P. C.	K	4	0.9727	0.9807	0.9723	0.9979
ESTATE A (R.R.I) ..	RUBBER	N	4	0.9845	0.9724	0.9656	0.9947
ESTATE A (R.R.I) ..	RUBBER	K	4	0.9991	0.9850	0.9989	0.9983
C 174 Third Harvest ..	M. S.	S	5	—	—	0.8066	0.9202
C 160 Thinings ..	P. C.	P	4	—	—	0.8238	0.9211
C 173 Third Harvest..	P. C.	N	4	—	—	0.7711	0.9209
C 189 Second Harvest	P. C.	N	4	—	—	0.9991	0.9766
C 159 Thinings ..	P. C.	P	4	—	—	0.9907	0.9972
C 194 Second Harvest	P. C.	K	4	—	—	0.9999	0.9853
C 160 First Harvest ..	P. C.	P	4	—	—	0.9605	0.9982
C 173 Thinings ..	P. C.	N	4	—	—	0.9286	0.9958

Note :— (1) Experiments on Paspalum Commersonii (P.C.) and Madicago Sativa (M.S.) have been conducted in a " Phytosolarium " at the Coconut Research Institute of Ceylon.

(2) R. R. I. : Rubber Research Institute of Ceylon.

The last approach is, obviously, not quite sound, although there may be instances where the quadratic model may fit better and validly so. The first two approaches, on the other hand, can under certain circumstances be quite justifiable. Generally the best attitude would be to consider these as alternative approaches in different situations.

In general, when one has nothing to go by—such as some ancilliary information regarding expected broad trends in the yield pattern in the particular set of circumstances—and when the number of levels of fertilizer tested is too few to decipher any regular or irregular tendencies in the observed data, it is recommended that one should resort to the more flexible type of mathematical model. On the basis of the present study, such a flexible model is provided by the square root equation.

If the data were based on several replications, which will bring the observed values close to the expected values and/or when there are (say) 5 or more levels of fertilizer, then the model that gives the better fit is to be preferred.

When the observed data show any depression in yield at higher levels of fertilizer, one has the option only between the square root and the quadratic—the other two models being obviously unsuitable, unless the experimenter is confident that the depression in yield is due to some other extraneous causes. The decision again rests on the better fit, provided a sufficient number of levels have being tested. If, however, the number of levels is too few (say, not exceeding four), and if one hopes to extraplote a bit, it is preferable to use the square root form. At any rate the quadratic form is to be avoided unless one is pretty certain that the pattern of depression after the point of maximum response runs symmetrically to the pattern of response before. If as mentioned earlier, any depression in yield or for that matter any other value, is known to be the obvious result of some extraneous factor independent of the fertilizer, then either this value should be dropped from consideration or some correction may be made (say) using some concomitant variable.

For the sake of completeness, it will be pertinent to give a few comments on the fitting of curves to data based on a minimum of three fertilizer levels—usually zero, one and two. It is undoubtedly desirable to have at least one fertilizer level more than the number of constants in the equation fitted, because otherwise the residual error is zero and as a result it is not possible to get any idea of the comparative goodness of fit of alternative models. But there are numerous situation where we have only three levels and we still need

to get some idea of the optimum fertilizer dosage or the yield curve. In such situations there is nothing biologically objectionable in fitting a curve to 3 points, provided one is conscious of the limitations of such curves and also takes some care with respect to the model to be used.

In passing, it will be of interest to note that the square root model, can be applied successfully to a wide variety of relationships showing diminishing returns. The author (1962) has found it superior to the quadratic form in problems of correcting (through multiple covariance analysis) for the curvilinear effect of the stand of palms on the plot yields in coconut and also for the curvilinear effect of the bearing age of coconut palms on their yields. The reduction in the "error" through this approach has been considerable.

SUMMARY

Some popular notions regarding the generalised fertilizer response pattern are reviewed. It is explained that under field conditions, the response curve, relevant to problems of estimating optimum fertilizer dosages, exhibits itself only as a restricted or truncated form of the general s-shaped response curve—namely the "increasing—decreasing" or concave to the abscissae type of curve, which itself may take any one of four specific forms or their intermediates.

Four popular mathematical models used in fitting such curves are given. These are compared on the basis of mathematical considerations through three accepted econometric criteria applicable to production functions and also on the basis of application on experimental data. Both on the basis of mathematical considerations and on the basis of results of application on experimental data, it is noted that (1) the polynomial models are more generally applicable (2) among the polynomial models, the square root model is the more adaptable, and (3) there are situations in which any one of the four models may be better.

Certain hints of guidance in the selection of a model for fitting fertilizer response curves are given.

Taking these facts into consideration, if one is confronted with the question of deciding on a universally applicable or a standard model for fitting curves to fertilizer responses or for that matter any responses showing diminishing returns, it would be reasonable to suggest that the square root model is relatively the most acceptable.

ACKNOWLEDGEMENTS

I am deeply indebted to Dr. S. C. Pearce of East Malling Research Station for the invaluable advice received in the preparation of this paper ; and also to Messers G. Karunasena and P. G. F. Fernando (Division of Biometrics, Coconut Research Institute of Ceylon) for the statistical work and the preparation of the typescripts.

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The Relationship between Chemical and Physico-Chemical Characteristics of Paddy Soils in the Dry State and on Continued Submergence*

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THE Chemical and biological processes that take place in a paddy soil when it is submerged are of a dynamic character. Most of the experiments carried out so far by Soil Chemists on paddy soils have been done with the rice plant in situ ; therefore the variations in the Chemical and Physico-Chemical characteristics of paddy soils on submergence in the absence of the rice plant have not been observed and recorded. Three important influences of the rice plant on the soil are :— (*a*) the exudation of oxygen by the rice roots which maintains an oxidized rhizosphere which influence the soil ; (*b*) the decaying dead roots make a significant contribution towards the soil organic matter, which in turn intensifies reductive processes in the soil ; (*c*) the absorption of nutrients from the soil. A study of the variations in the chemical regime in the absence of the rice plant therefore appears to be an important aspect of soil nutritional relationships of paddy soils.

The main object of this investigation was to study the variations and relationships between the chemical and physico-chemical characteristics of paddy soils in the dry state and on continued submergence.

MATERIALS AND EXPERIMENTAL PROCEDURE

Twenty soils comprising of the following seven groups were studied.

1. Strongly acid lateritic rice soils of the ultra wet zone.
2. Strongly acid humic rice soils.

* A paper read at the Eighth Sessions of the Working Party on Rice Soils, Water and Fertilizer Practices of the International Rice Commission held in New Delhi, December, 1961.

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3. Ground water podzolic rice soils.
4. Acid lateritic rice soils of the wet zone.
5. Non-Lateritic rice soils of the dry zone.
6. Calcareous rice soils.
7. Non-Lateritic clayey rice soils.

The experiment was carried out under greenhouse conditions in glazed pots with a side opening at the bottom. The pots were filled to the brim and the 2″ of standing water was maintained by daily addition of distilled water.

The dry soil was analysed for carbon, nitrogen, cation exchange capacity, total exchangeable cations, free iron oxide, total iron, easily reducible manganese, total manganese, available silica, available phosphorous, pH and mechanical analysis.

After submergence the following determinations were made in the wet soil at intervals of 2 weeks initially and later at intervals of 4 weeks :— Ammonia, Iron, Manganese, Oxidisable Matter, pH and Redox Potential.

Water percolates were also analysed at intervals for Ammonia, Nitrate, Iron, Manganese, Oxidisable Matter and Conductivity.

pH was measured in situ by placing 2 blank pltinum electrodes seated permanently in each pot 6 in. below the surface of the soil. They were placed near the centre and at a distance of 3 in. apart from each other. The potentials were measured with a Beckman pH meter Model G using a saturated calomel electrode.

Oxidisable matter includes Fe^{+2}, No_2^1 and S^1 among the inorganic constituents and soluble organic matter that is oxidised under relatively mild conditions. This determination would give a measure of the reducing capacity. This is a relative determination and has only comparative significance.

The method is based on the oxidation of the sample with potassium permanganate under standard conditions. The sample (the volume used varied from 1.0 ml to 10 ml) was added to a mixture of 10 ml. of 0.01 N $KMnO_4$, and 10 ml of 1 : 3 H_2SO_4 with sufficient water to make a total volume of 100 ml, in a 250 ml conical flask. The flask was heated in a boiling water bath for 30 minutes along with a blank. By this procedure the factors (strength of $KMnO_4$, acidity of the medium and time of digestion) on which the figure for oxidisable matter depends, were kept nearly constant. Immediately after the digestion

10 ml of 0.01 N Ammonium oxalate solution was added and the excess oxalate back titrated against 0.01N $KMnO_4$. The difference between this reading and the blank reduced to an equivalent of 10cc of the percolate was taken as an index of the concentration of oxidisable matter or the reducing capacity.

About 50 grms of the soil were extracted with a glass tube 24 in. long and 2 cm diameter by inserting it into the pot in a circular motion. This was used for the analysis of the wet soils.

pH and moisture determinations were run on the same sub-sample. The sample was transferred to a tared 50 ml. beaker and the weight of the moist soil quickly determined. An equal weight (volume) of oxygen free distilled water was added, the beaker swirled and the pH determined with a glass electrode. The soil adhering to the electrodes was washed into the beaker with a jet of water. After expulsion of the bulk of water on a water bath the soil was dried further in an oven at 105° and the moisture percentage determined.

The remaining soil was transferred into a 500 ml. conical flask which had been previously weighed. The weight of the moist soil quickly determined ; a rough allowance was made for the moisture content on the basis of preliminary experience, and measured amounts of Morgan's solution added to give a soil extractant ratio of approximately 1 : 5. The flasks were allowed to stand for 24 hours with occasional swirling and the solution filtered through fluted filter paper. This solution was used for the determination of ammonia, iron, manganese and oxidisable matter. Morgan's solution will extract ferrous iron and not ferric iron. These figures will characterise the extent of reduction of the soil. With the aid of the amount of Morgan's solution added and the moisture content of the soil all figures are reduced to ppm of the dry soil. The values for oxidisable matter are reduced to ccs of 0.01N $KMnO_4$ per grm of dry soil.

Standard methods were used for the other determinations.

RESULTS AND DISCUSSION

Dry Soils. The analysis of the dry soils is given in Table 1. The values obtained readily permit the soils to be grouped into seven classes. The average of the seven groups are given in Table II.

pH. The average pH value for the Ultra wet zone soils is 4.84 ; for the wet zone it is 5.65 ; for the dry zone 7.26 and for the calcareous soils it is 7.78. The pH rises from ultra wet zone to the dry zone.

Carbon. The carbon values take an opposite trend. It is high for the ultra wet zone soil with 2.4 per cent, for the wet zone it is 1.3 per cent for the dry zone it is 1.1 per cent calcareous soils has a value of 0.8 per cent. The humic soils is highest with 10.4 per cent and ground water podzolic soils is lowest with an average of 0.45.

Nitrogen. The Nitrogen percentages follow the same trend as the carbon values. It is 0.17 per cent for the ultra wet zone soils, 0.11 per cent for the wet zone soils, 0.09 per cent for the dry zone soils and 0.09 for calcareous soils. The Nitrogen content of the humic soils is highest with 0.52 per cent and lowest for the ground water podzols with 0.035 per cent.

Cation Exchange Capacity. The cation exchange capacities increases with the rise in pH ; 7.7 for the ultra wet zone soils, 11.9 for the wet zone soils, 15.8 for the dry zone soils. It has a high value of 20.8 for humic soils and a very low value of 1.3 for the ground water podzols.

Total Exchangeable Bases. The total exchangeable bases also increase with the rise in pH. It is 1.5 for the ultra wet zone, 6.1 for the wet zone soils, 8.9 for the dry zone soils and 10.5 for the calcareous soils. It is lowest for the ground water podzols with 0.75.

Available Silica. Available silica also increases with pH. It is 23.5 ppm for the ultra wet zone soils, 76.4 for the wet zone soils, 145.2 for the dry zone soils. It is lowest for the ground water podzols with 6.75 ppm while the humic soils contain 33.5 ppm. The calcareous soils and clayey soils have high values of 143.2 and 142.3 ppm respectively.

Free Fe/Total Fe percentage. The percentage of free iron to total iron decrease with rise in pH. It is highest with 82 per cent for the ultra wet zone, with values of 64 and 49 per cent for the wet zone and dry zone respectively. The humic soils too contain a high value of 70 per cent while ground water podzols are lowest with 38 per cent.

This could be expected as the amount of weathering and leaching is high in the ultra wet zone, less in the wet zone and least in the dry zone. The humic soils too contain a high percentage of free iron to total iron due to the high carbon content which gives rise to organic acids. This value is least for the podzols as they are very highly weathered leached sandy soils.

General. The soils of the ultra wet zone which are strongly acid, low in cation exchange capacity indicate a kaolinite clay.

The non-lateritic rice soils of the dry zone with an average pH of 7.26, high cation exchange capacity of 65.2 m.e. per 100 gms clay, high total exchangeable bases of 37.5 m.e. per 100 gms clay, a high silica content of 145.2 ppm indicate a fair proportion of montmorillonitic clay.

Water Percolates and Wet Soils. The analyses of the water percolates are given in table III. The averages of the groups are given in table IV. The analysis of the wet soils are given in table V and their averages are given in table VI. These are graphically shown in figures 1 to 12.

General. There was a fall in redox potential, an increase of pH with time and an almost total disappearance of nitrate within 14 days of submergence. Ammonia, reduced iron, reduced manganese, oxidisable matter and conductivity reached a peak and then decreased.

Ammonia-Water Percolates. The initial values obtained after a day's submergence run parallel to the initial nitrogen content of the dry soils. It is highest with 33 ppm for the ultra wet zone, with 17 ppm for the wet zone and 6 ppm for the dry zone, while humic soils, ground water podzols, calcareous soils and clayey soils contain 30, 23, 9.5 and 14 ppm respectively.

The peak values too follow the same trend. It is highest with 132 ppm for the ultra wet zone, with 49 ppm for the wet zone and 29 ppm for the dry zone, while the humic soils, ground water podzols, calcareous soils and clayey soils reach 92, 59, 37 and 36 ppm.

The final values for ammonia too take the same trend.

The difference between the initial and maximum value will indicate the degree of ammonification. These values too follow the same trend. It is highest with 99 ppm for the ultra wet zone, with 32 ppm for the wet zone and 23 ppm for the dry zone ; while humic soils, ground water podzols, calcareous soils, and clayey soils have values of 62, 36, 27.5 and 22 ppm for the degree of ammonification.

The differences between the maximum value and final value will indicate the degree of denitrification. These values too follow the same trend. It is highest with 78 ppm for the ultra wet zone, with 22 ppm for the wet zone and 18 ppm for the dry zone ; while humic soils, ground water podzols, calcareous soils and clayey soils have values of 42, 43, 23.5 and 25 ppm for the degree of denitrification.

When a soil is submerged the oxygen supply is almost completely cut off and anaerobic decomposition of organic matter sets in. Ammonia is the most important product of anaerobic decomposition.

It is postulated that ammonia formed in the bulk of the soil diffuses upwards on a concentration gradient. When it reaches the oxidised surface layer it is converted to nitrate. The nitrate thus formed again on a concentration gradient diffuses downwards and when it reaches the reducing layers of the soil denitrification takes place. During denitrification nitrate acts as an oxygen donor to oxidise the constituents of the soil viz. reduced iron, reduced manganese, oxidisable matter, etc., and nitrogen escapes as a gas. It may be mentioned here that there was no detectable amounts of ammonia or nitrate in the supernatent liquid and there was no detectable amounts of nitrate in the percolates. This indicates that the nitrate formed in the oxidising layer readily diffuses downwards and is quickly denitrified. Ammonification, nitrification and denitrification take place simultaneously. During initial stages of submergence there is more ammonification than denitrification, thus ammonia values rise ; later there is more denitrification than ammonification and the values for ammonia fall.

At the end of the experiment the soils were air dried and analysed for carbon and nitrogen. Eight soils which gave values lower than those obtained before submergence are given below :—

	Before Submergence			*After Submergence*		
	C.	*N.*	*C/N*	*C.*	*N.*	*C/N*
1. Panagoda	3·4	·21	16	3·1	·19	16
2. Bombuwela Peaty	10·4	·52	20	9·8	·50	20
3. Bibile	0·6	·07	8·5	0·6	·06	10
4. Peradeniya	2·4	·15	16	2·3	·14	16
5. Kundasale	0·8	·09	9	0·8	·08	10
6. Matale	1·3	·13	10	1·2	·12	10
7. Ambalantota 1	2·4	·19	13	2·3	·18	13
8. Ambalantota 2	2·2	·17	13	2·1	·16	13

1. Panagoda—net denitrification of 181 ppm in percolate and 163 ppm in the wet soil ;
2. Bombuwela Peaty—has a high initial nitrogen content of .52 ;
3. Bibile—C/N ratio before submergence is low—8.5 and it is raised to 10 ;
4. Peradeniya—has a net denitrification of 231 ppm in the wet soil ;
5. Kundasale—C/N ratio before submergence is low—9.0 and it is raised to 10 ;
6. Matale—has a net denitrification of 243 ppm in the wet soil ;
7. Ambalantota 1—has a high initial nitrogen content of .19 ;
8. Ambalantota 2—has a high initial nitrogen content of .17.

A high initial nitrogen content or a high value for net denitrification either in the wet soil or in the percolate or a low C/N ratio will show detectable losses of nitrogen on submergence by the analyses of dry soils.

These findings are of very important practical significance. Hitherto it was believed that deep-placement of ammonia fertilizers will prevent loss of nitrogen due to denitrification. It could be inferred from this experiment that even with deep-placement of ammonium fertilizers denitrification still takes place ; hence the rate and time of application of ammonium fertilizers are important. In certain instances denitrification is beneficial as it oxidises the reduced products such as ferrous iron which may reach toxic proportions, and keeps them at low concentrations. The peak values of the percolates are reached in about 28 days ; during this period the young rice roots are subjected to an influx of increasing reduced products. The practical significance of this is that the toxicity due to reduced products, which are observed in certain parts of the ultra wet zone, may be averted by keeping the soils submerged for some length of time till the peak value is reached before transplanting.

Reduced Iron-Water Percolates. The initial values are low as very little ferrous iron could be expected on a day's submergence. The maximum values are highest for the ultra wet zone with 252 ppm and as expected it is lower for the wet zone 159 ppm, still lower for the dry zone 38 ppm and least for the calcareous soils with 7 ppm. The humic soils, ground water podzols, and clayey soils have maximum values of 158, 75 and 91.

The final values too follow the same trend.

The difference between the initial and maximum values gives the amount of iron reduced and brought into solution. The differences between the maximum and final values give the amount of ferrous iron oxidised. These values too follow the same trend.

The oxidation of the once reduced iron could be attributed to three causes :

(1) Denitrification.
(2) Oxidation and precipitation in the surface layer where oxidising conditions prevail.
(3) By the slow diffusion of atmospheric oxygen.

Of these oxidation due to denitrification appears to be considerable.

Reduced Manganese-Water Percolate. Manganese does not behave like ammonia and reduced iron. It appears to be closely connected

with the initial pH, total manganese content of the soil and the carbon content. When considering the maximum manganese values of the percolates it is evident that for manganese to come into solution there must be sufficient total manganese in the soil, a low pH and a certain amount of carbon. The highest value of 41.8 ppm is obtained for the wet zone where all these conditions are satisfied. Dry zone soils have 26.7 ppm with a high initial pH of 7.28. The ultra wet zone soils have 12.3 ppm as the total manganese content is low.

From the analyses of the dry soils, water percolates and wet soils it appears that the following soils may be deficient in manganese: Panagoda, Bombuwela Peaty and Bombuwela Sandy.

Oxidisable Matter-Water Percolate. Oxidisable matter which gives a measure of the reducing capacity of the percolate follows the same pattern of ammonia and reduced iron.

Conductivity-Water Percolate. Conductivity behaves differently from the rest as it measures the ionisable salts. It is highest for these clayey soils which may contain chlorides, then come the calcareous soils, dry zone soils, ultra wet zone soils, wet zone soils, humic soils and ground water podzols.

Wet Soils. The analyses of the wet soils are given in table V, and the average of the groups are given in table VI; these are graphically shown in figures VI to XII. The wet soils and more particularly their iron contents behave differently from the percolates.

Ammonia-Wet Soils. The initial values appear to depend on the nitrogen content of the dry soils. The maximum values are highest for the clayey soils, dry zone soils and humic soils. There is a similar trend for the final values. The difference between the initial values and the maximum values which will indicate the degree of ammonification that has taken place and the difference between the maximum values and final values which will indicate the amount of ammonia converted back to the original form too follow the same trend.

Reduced Iron, Reduced Manganese and pH-Wet Soils. Variation in pH demands special merit. There is a negative correlation between the initial pH and the increase in pH. The lower the initial pH the greater is the increase.

Initial values of iron seems to depend on the free iron oxide content. The maximum values and the final values depend on the total iron content. It is of great ecological importance to note that though the amount of iron reduced in the soil depends on its iron content, the

iron brought into solution depends on its pH. The lower the pH more iron is brought into solution. This is clearly shown in the table below :

	Maximum Fe ppm in percolate	*Maximum Fe ppm in wet Soils*	*pH of dry Soils*
Group 1	252 ..	2,157 ..	4·84
Group 2	158 ..	3,042 ..	4·65
Group 3	75 ..	210 ..	5·47
Group 4	159 ..	4,885 ..	5·65
Group 5	38 ..	1,825 ..	7·26
Group 6	7 ..	930 ..	7·78
Group 7	91 ..	5,162 ..	6·22

The clayey soils with a reduced iron content of 5,162 ppm has only 91 ppm in the percolate with a high pH of 6.22, whereas the ultra wet zone soils with a reduced iron content of 2,157 ppm (less than half that of clayey soils) has as much as 252 ppm in the percolate with a low pH of 4.84.

The peak values of reduced iron in the percolates are correlated to pH, the largest values are reached with the lowest pH and vice versa or in other words the amount of iron brought into solution is proportional to the increase in pH.

From the fore-going results it is evident that duration of submergence as well as the inter-relationships between chemical and physico-chemical properties play a significant role in the chemical equilibria which result at different stages of submergence. The analysis of paddy soils under fields conditions—wet state—is rather impractical as it is not possible to freeze the chemical equilibria. Paddy soils in the wet state have been studied under conditions which permit such analysis. From this experiment it is evident that the status of any constituent for a specific soil group depends mainly on the duration of submergence. Once these curves are constructed under greenhouse conditions for specific soil groups the chemical and physico-chemical environment which the rice roots will be subjected to at different stages of their growth are known. The analysis of paddy soils in the dry state is necessary to characterize the soil group and is alone sufficient in predicting the chemical and physico-chemical status on submergence.

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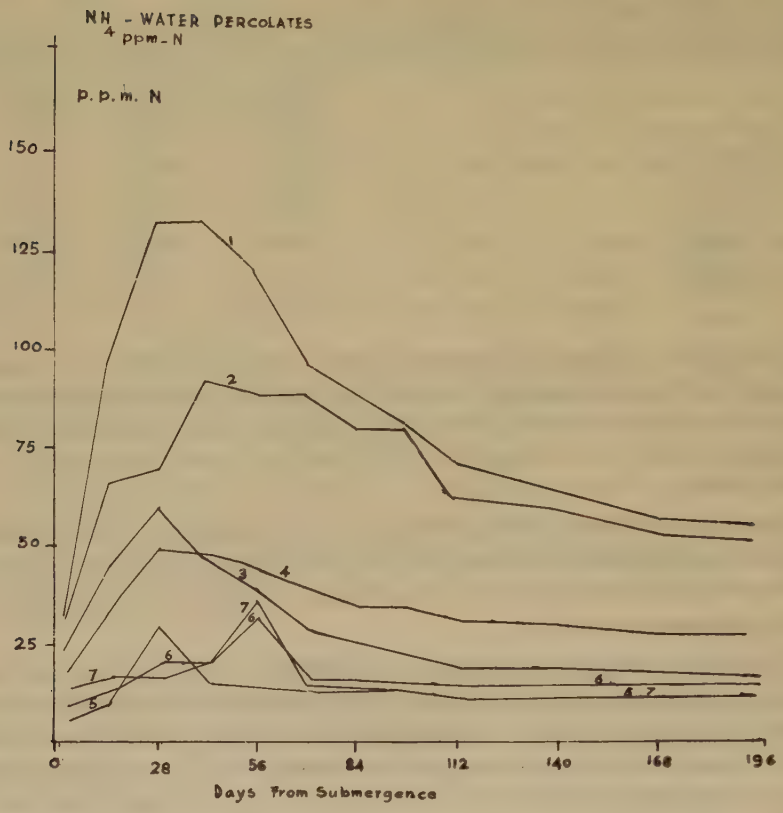

FIGURE 1

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

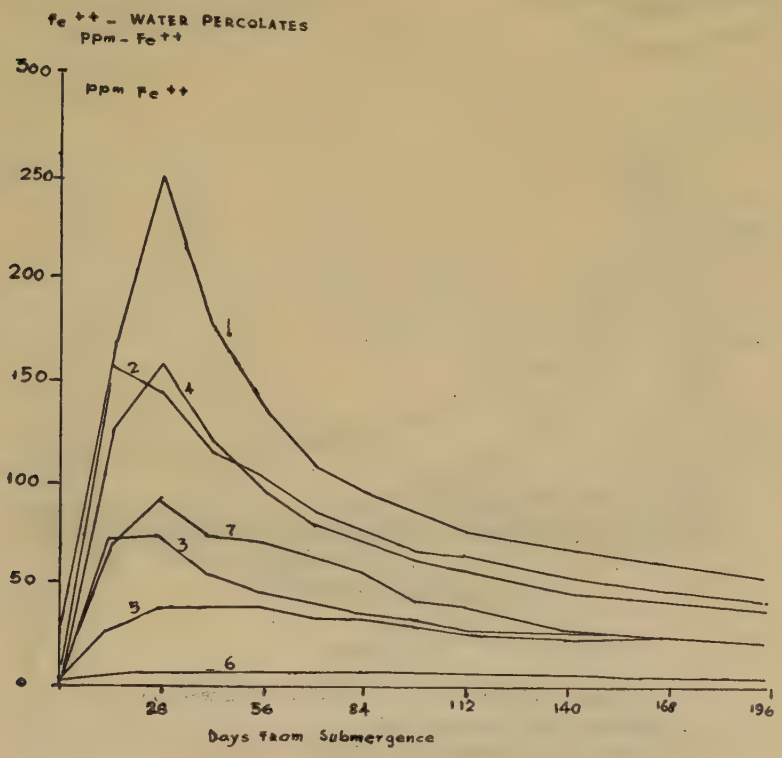

FIGURE 2

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

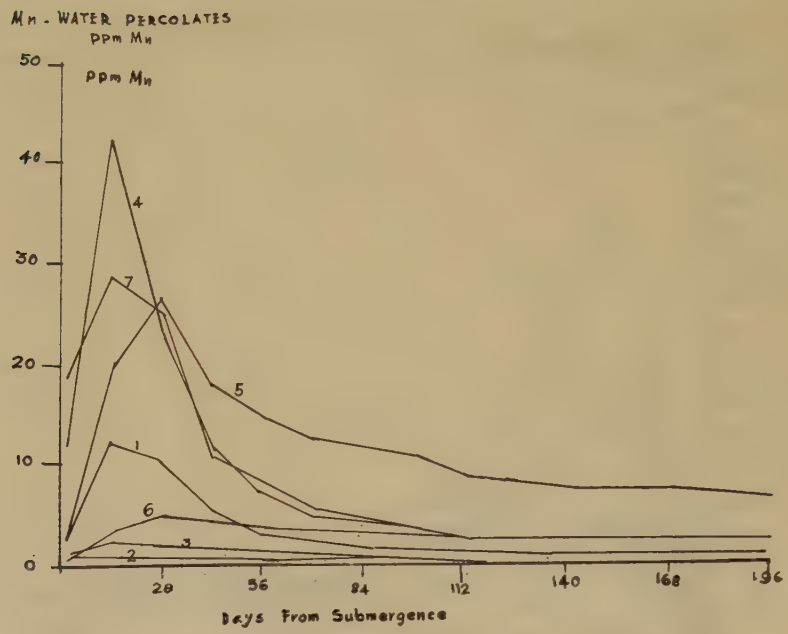

FIGURE 3

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

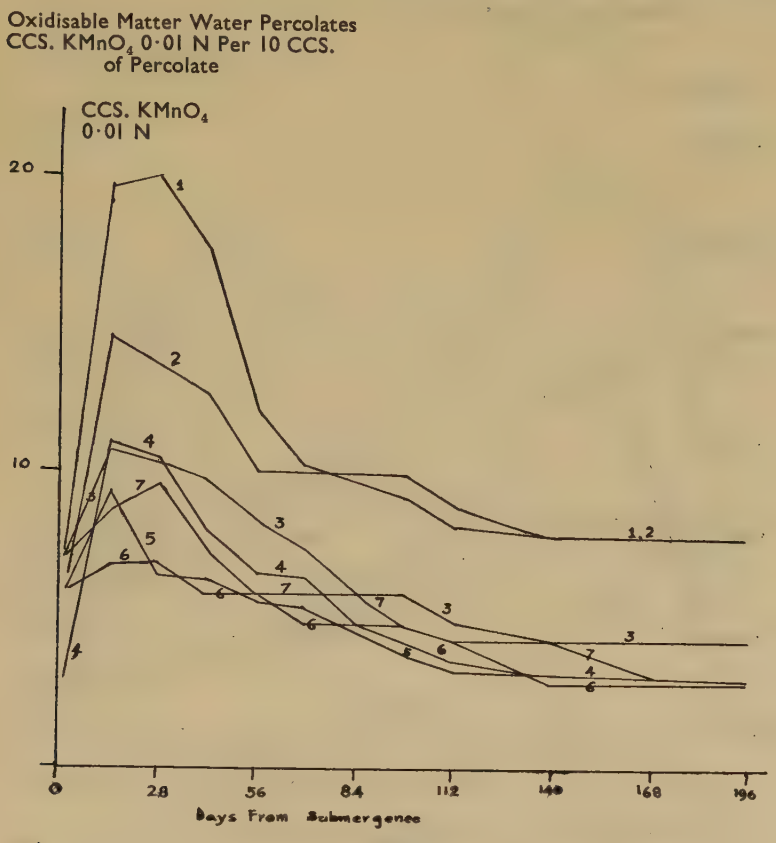

FIGURE 4

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

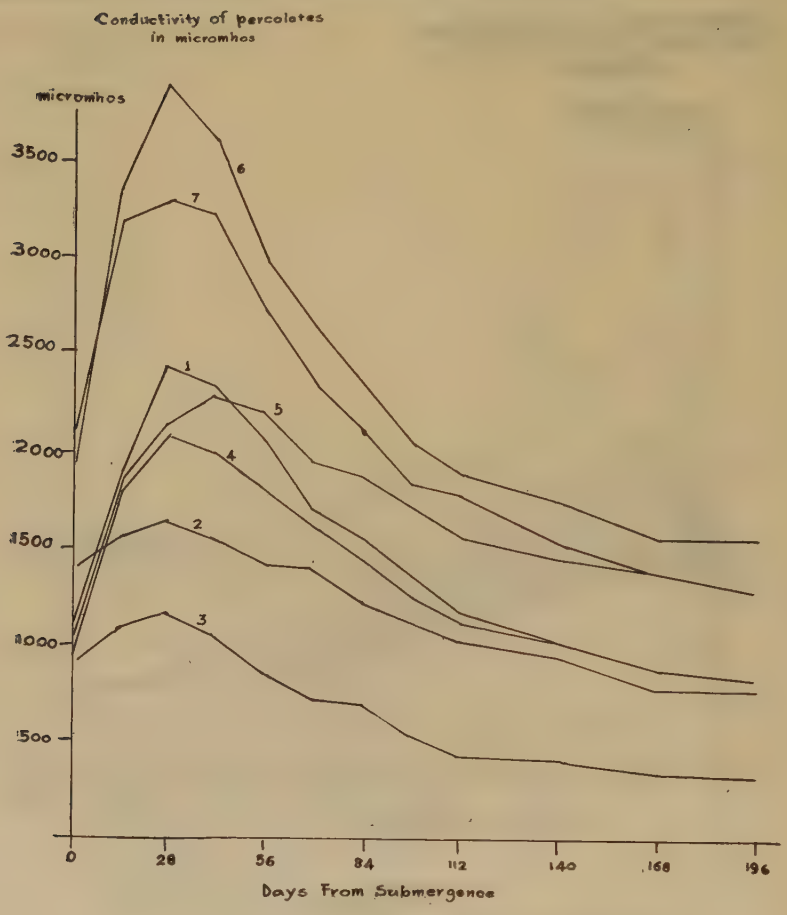

FIGURE 5

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

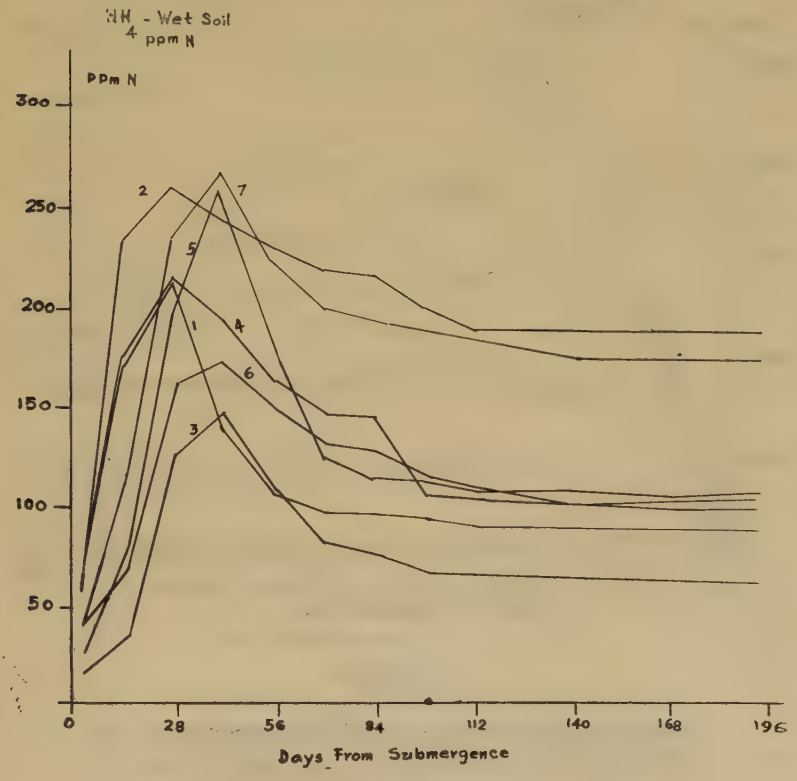

FIGURE 6

1. Strongly acid lateritic rice soils of the "ultra" wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

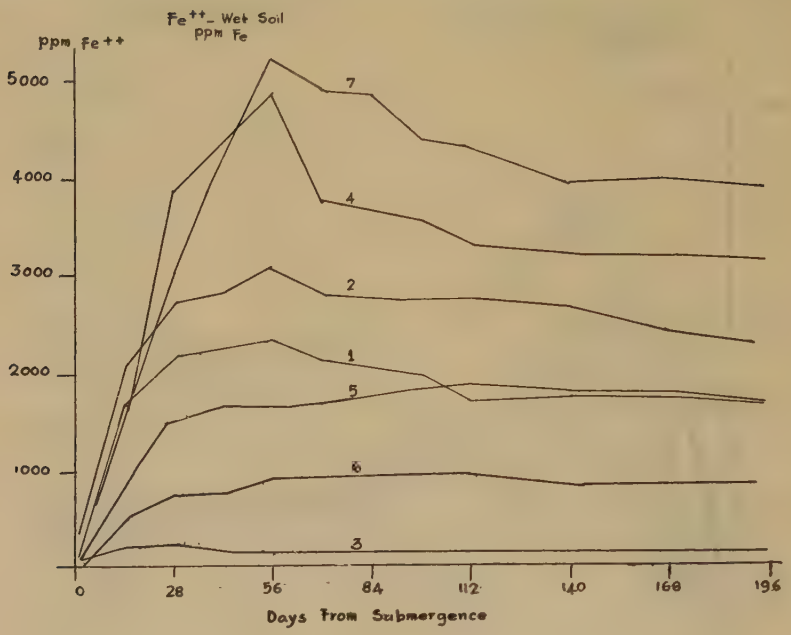

FIGURE 7

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

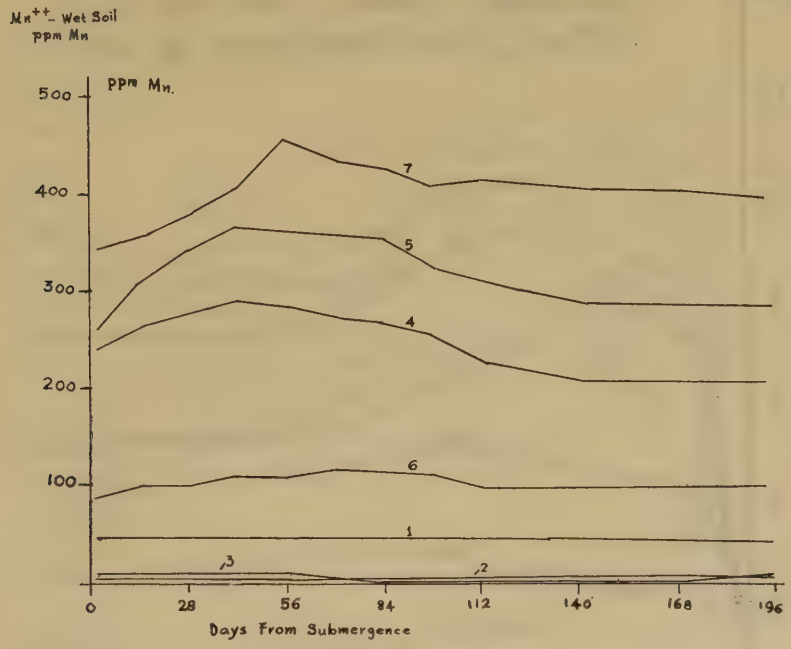

FIGURE 8

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

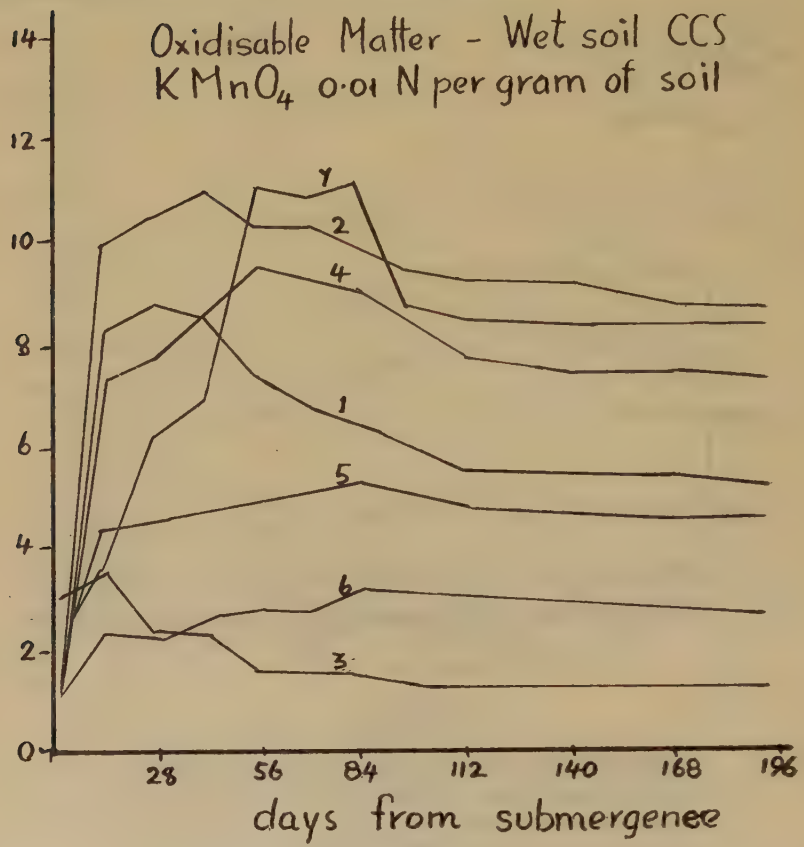

FIGURE 9

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

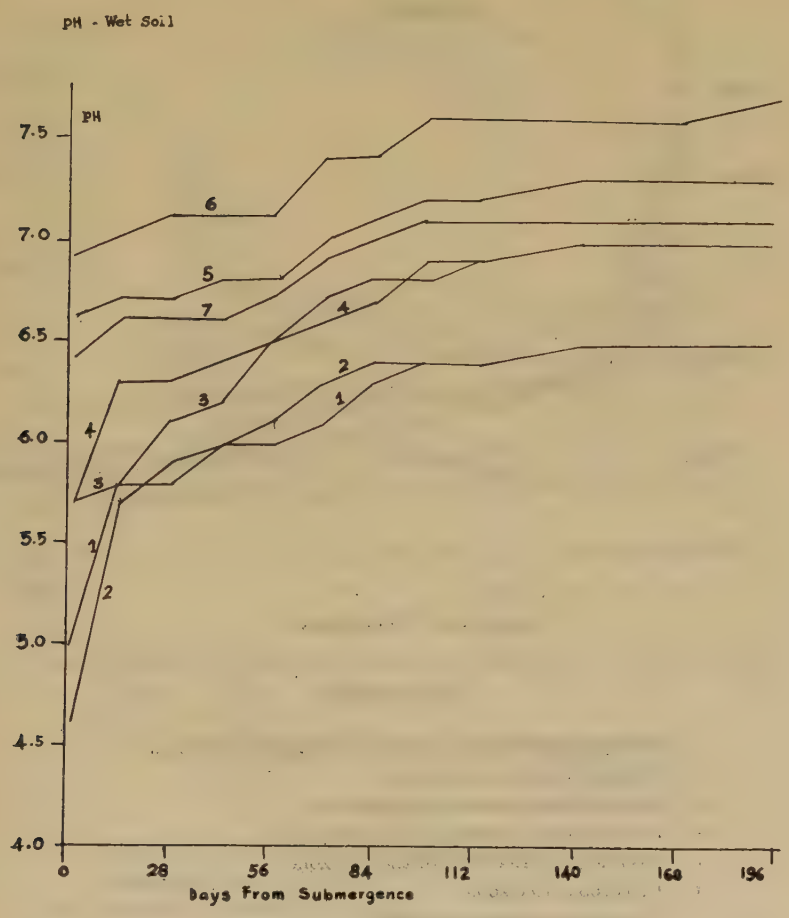

FIGURE 10

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

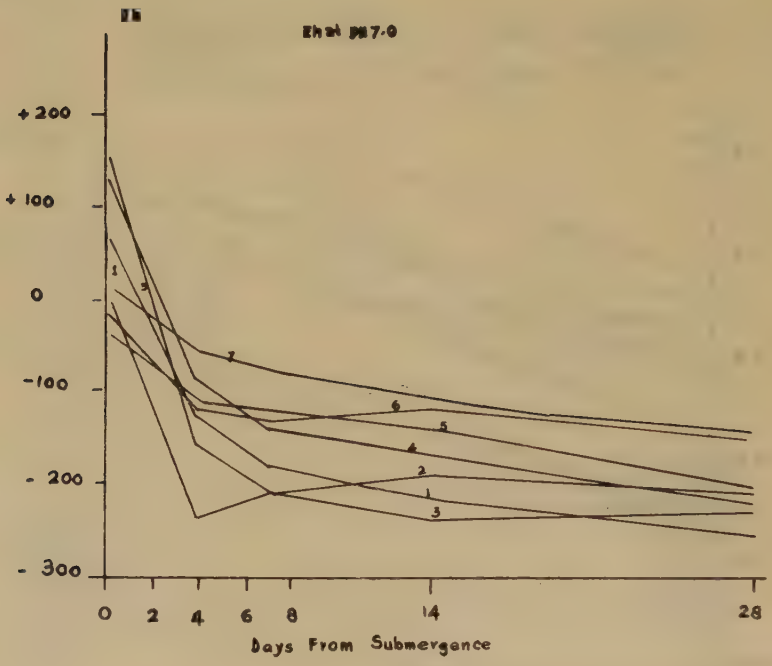

FIGURE 11

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

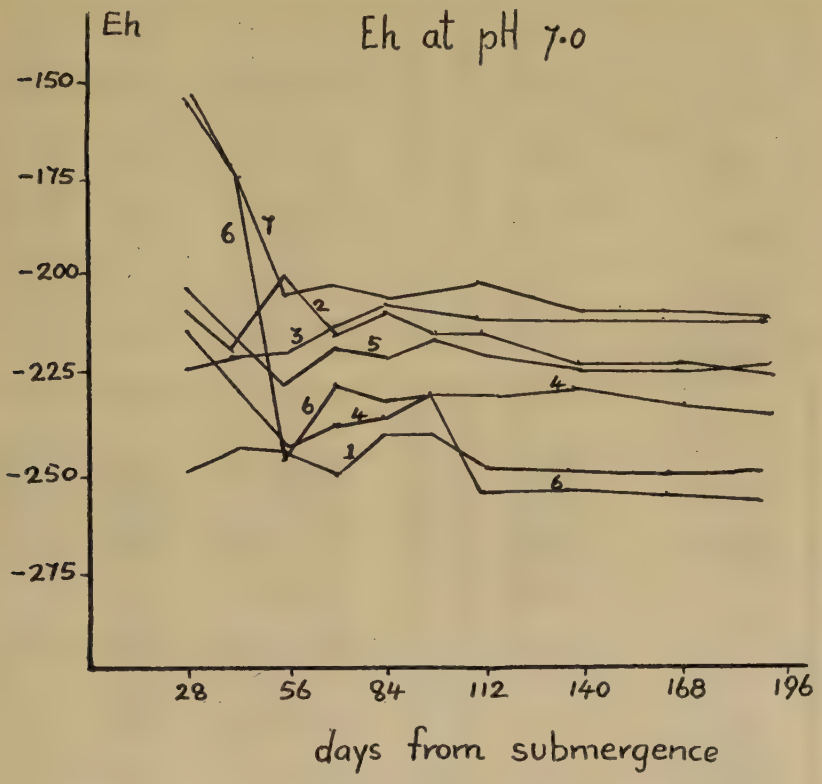

FIGURE 12

1. Strongly acid lateritic rice soils of the ultra wet zone
2. Strongly acid humic rice soils
3. Ground water podzolic rice soils
4. Acid lateritic rice soils of the wet zone
5. Non-lateritic rice soils of the dry zone
6. Calcareous rice soils
7. Non-lateritic clayey rice soils

TABLE I—Dry Soils

	pH	Carbon %	N %	Carbon / N	C.E.C.m.e. per 100 grms Soil	T.E.C.m.e. per 100 grm Soil	Free Fe %	Total Fe %	Easily Reducible Mn %	Total Mn %	Free Fe/Total Fe %	Easily Reducible Mn/Total Mn %	Available P ppm.	Available Sil. ppm	Coarse Sand %	Fine Sand %	Silt %	Clay %
(1) *Strongly Acid lateritic Rice Soils of he ultra Wet Zone—*																		
1. P'anagoda	4·86	3·4	·21	16	7·9	0·7	0·52	0·86	·00022	·00640	60	3·4	37·2	14·5	42·8	29·8	6·3	18·0
2. Mirigama	4·65	1·9	·17	11	9·1	1·9	4·35	4·80	·00070	·04600	91	1·5	4·7	39·0	25·2	25·8	8·5	37·0
3. Mapalana	4·70	2·5	·17	15	7·7	1·6	1·42	1·69	·00065	·00470	84	13·8	15·6	20·5	35·0	34·8	5·5	23·5
4. Karapincha	5·14	1·8	·12	15	6·2	1·7	1·98	2·75	·00020	·01300	72	1·5	4·5	20·0	43·4	31·6	6·5	17·0
(2) *Strongly Acid Humic Rice Soils—*																		
1. Bombuwela Peaty ..	4·65	10·4	·52	20	20·8	2·5	1·40	2·00	·00044	·00500	70	8·8	12·5	33·5	14·2	15·6	16·9	38·6
(3) *Ground Water Podzolic Rice Soils—*																		
1. Bombuwela Sandy ..	5·62	0·6	·04	15	1·2	0·7	0·20	0·58	·00019	·00400	34	4·8	7·1	7·0	58·5	35·5	3·0	1·0
2. Batticaloa	5·32	0·3	·03	10	1·4	0·8	0·25	0·63	·00066	·08900	40	0·7	5·1	6·5	49·4	39·7	5·8	3·8
(4) *Acid lateritic Rice Soils of the Wet Zone—*																		
1. Welimada	5·30	1·5	·12	12·5	11·5	4·9	4·35	5·13	·00058	·05100	85	1·2	7·5	83·0	29·2	30·7	12·4	23·5
2. Bibile	5·65	0·6	·07	8·5	5·0	2·8	1·38	2·05	·00132	·03400	67	3·9	5·9	32·5	35·3	41·2	6·5	17·0
3. Peradeniya	5·55	2·4	·15	16	18·6	5·5	5·28	7·63	·00122	·08500	69	1·4	6·5	90·0	13·5	25·2	26·0	30·0
4. Kundasale	6·60	0·8	·09	9	13·0	9·8	1·50	4·44	·00013	·06100	34	0·2	13·1	128·2	35·5	34·5	6·5	23·5
5. Matale	5·38	1·3	·13	10	14·1	8·0	2·62	4·25	·00056	·04770	62	1·7	8·6	73·0	34·8	26·5	7·0	27·0
6. Nalanda	5·41	1·0	·10	10	9·0	5·5	2·85	4·50	·00100	·05200	63	1·9	12·6	51·5	30·6	40·8	5·0	23·0
(5) *Non-lateritic Rice Soils of the Dry Zone—*																		
1. Polonnaruwa	7·30	1·3	·11	12	14·5	10·5	0·92	2·63	·00110	·07300	35	1·5	12·9	98·0	24·3	46·2	7·5	20·0
2. Hingurakgoda	7·47	1·3	·10	13	16·7	10·1	0·65	2·37	·00033	·02800	27	1·2	5·0	129·9	25·0	44·0	3·0	25·0
3. Maha Illuppallama Red ..	6·88	0·8	·07	11	14·1	5·3	2·30	3·31	·00084	·06900	69	1·2	8·3	183	30·4	30·6	8·7	26·8
4. Maha Illuppallama Grey ..	7·39	0·9	·09	10	17·9	9·7	1·00	3·23	·00122	·05700	31	2·1	6·3	170	14·4	49·8	5·4	26·1
(6) *Calcareous Rice Soils—*																		
1. Jaffna	7·78	0·8	·09	9	12·0	10·5	1·05	1·99	·00096	·02400	53	4·0	22·6	143·2	35·1	38·2	8·2	14·8
(7) *Non-lateritic Clayey Rice Soils—*																		
1. Ambalantota 1.	6·43	2·4	·19	13	26·7	15·7	3·25	5·88	·00084	·08200	55	0·66	20·0	156·5	9·3	23·4	11·5	50·0
2. Ambalantota 2.	6·02	2·2	·17	13	26·7	15·9	3·72	6·00	·00043	·08100	62	0·5	15·6	128·2	7·4	20·8	7·8	58·5

TABLE II—Dry Soils—Averages

	pH	Carbon %	N%	Clay %	C.E.C.m.e. per 100 grm. Soil	T.E.C.m.e. per 100 grm. Soil	Available Silica ppm.	Free Fe / Total Fe %	Total Mn. %
1. Strongly Acid lateritic Rice Soils of the Ultra Wet Zone	4·84	2·4	·17	23·9	7·7	1·5	23·5	82	·01752
2. Strongly Acid Humic Rice Soils (one soil)	4·65	10·4	·52	38·6	20·8	2·5	33·5	70	·00500
3. Ground Water Podzolic Rice Soils	5·47	0·45	·035	2·4	1·3	0·75	6·75	38	·04650
4. Acid lateritic Rice Soils of the Wet Zone	5·65	1·3	·11	24·0	11·9	6·1	76·4	64	·05512
5. Non lateritic Rice Soils of the Dry Zone	7·26	1·1	·09	24·5	1o·8	8·9	145·2	49	·05675
6. Calcareous Rice Soils (one soil)	7·78	0·8	·09	14·8	12·0	10·5	143·2	53	·02400
7. Non-lateritic Clayey Rice Soils	6·22	2·3	·18	54·3	26·7	15·8	142·3	59	·08150

TABLE III—Water Percolates

	Initial NH_4 ppm N	Max. NH_4 ppm N	Final NH_4 ppm N	Diff. initial & max. NH_4 ppm N	Diff. max. & final NH_4 ppm N	Initial Fe ppm	Max. Fe ppm	Final Fe ppm	Diff. initial & max. Fe ppm	Diff. Max. & final Fe ppm	Initial Mn ppm	Max. Mn ppm	Final Mn ppm	Diff. initial & max. Mn ppm	Diff. max. & final Mn ppm	Initial oxy: M.	Max. oxy. M.	Final oxy. M.	Diff. initial & max. ox. M.	Diff. max. & final ox. M	Cond. initial micromhos	Cond. max. micromhos	Cond. final micromhos	Cond. diff. initial & max. micromhos	Cond. diff. max. & final micromhos
(1) *Strongly Acid Rice soils of the Ultra Wet Zone*—																									
1. Panagoda ..	80	256	75	176	181	6·5	154	25	147·5	129	0·1	0·4	0	·3	·4	8·6	22·5	13·0	13·9	9·5	1611	3515	983	1904	2532
2. Mirigama ..	12·5	70	43	57·5	27	0·5	350	56	349·5	294	7·0	42	1·8	35	40·2	9·2	21·6	4·0	12·4	17·6	736	2000	663	1264	1337
3. Mapalana ..	9·5	102	50	92·5	52	10	295	82	285	213	1·6	3·0	0	1·4	3·0	7·1	24·5	10·0	17·4	14·5	460	1966	800	1506	1166
4. Karapincha ..	28	116	46	88	70	1·0	218	56	217	162	0·8	3·7	0·8	2·9	2·9	5·3	16·7	5·0	11·4	11·7	840	2231	928	1391	1303
(2) *Strongly Acid Humic Rice Soils*—																									
1. Bombuwela Peaty ..	30	92	50	62	42	18·5	158	45	139·5	113	0·4	0·4	0	0	·4	6·9	14·7	8·0	7·8	6·7	1389	1604	773	215	831
(3) *Ground Water Podzolic Rice Soils*—																									
1. Bombuwela Sandy ..	27	76	15	49	61	2	67	18	65	49	0·4	0·6	0	·2	·6	4·3	10·8	4·0	6·5	6·8	1111	1415	349	304	1066
2. Batticaloa ..	19	41	17	22	24	1·0	82	25	81	57	1·9	3·7	0·5	1·8	3·2	10·0	10·8	5·0	0·8	5·8	672	879	294	207	585
(4) *Acid lateritic Rice Soils of the Wet Zone*—																									
1. Welimada ..	8	41	30	33	11	0	137	50	137	87	8·8	32·5	1·3	23·7	31·2	3·7	16·7	3·0	13·0	13·7	1348	1877	1009	529	868
2. Bibile ..	60	90	40	30	50	0·5	152	32	151·5	120	20·5	78·0	2·0	57·5	76	3·3	19·6	2·0	16·3	17·6	2178	2937	1009	759	1928
3. Peradeniya ..	12	58	36	46	22	0·5	160	33	159·5	127	4·0	41·2	0·6	37·2	40·6	3·3	8·8	4·0	5·5	4·8	475	1547	678	1072	869

| | | |

TABLE IV—Water Percolates—Averages

	Initial NH_4 ppm N	Max : NH_4 ppm N	Final NH_4 ppm N	Diff : initial & max : ppm N	Diff : max : & final ppm N	Initial Fe ppm	Max : Fe ppm	Final Fe ppm	Diff : initial & max : Fe ppm	Diff : Max : & final Fe ppm	Initial Mn ppm	Max : Mn ppm	Final Mn ppm	Diff : initial & max : Mn ppm	Diff : max : & final Mn ppm	Initial oxy : matter	Max : oxy : matter	Final oxy : matter	Diff : initial & max : oxy : matter	Diff : max : & final oxy : matter	Cond : initial micromhos.	Cond : max : micromhos.	Cond : final micromhos.	Cond : diff : initial & max : micromhos.	Cond : diff : max : & final micromhos.
1. Strongly Acid lateritic Rice Soils of the Ultra Wet Zone ..	33	132	54	99	78	5·0	252	55	247	197	2·4	12·3	·7	9·9	11·6	7·6	19·9	8·0	12·3	11·9	912	2407	844	1495	1563
2. Strongly Acid Humic Rice Soils (one soil) ..	30	92	50	62	42	18·5	158	45	139·5	113	0·4	0·4	·0	·0	·4	6·9	14·7	8·0	7·8	6·7	1389	1604	773	215	831
3. Ground Water Podzolic Rice Soils ..	23	59	16	36	43	·2	75	22	73	53	1·2	2·2	·3	1·0	1·9	7·2	10·8	4·5	3·6	6·3	892	1147	322	255	825
4. Acid lateritic Rice Soils of the Wet Zone ..	17	49	27	32	22	·3	159	40	1587	119	11·9	41·8	2·0	29·9	39·8	3·0	11·1	3·2	8·1	7·9	997	2058	846	1061	1212
5. Non-lateritic Rice Soils of the Dry Zone ..	6	29	11	23	18	·4	38	23	37·6	15	2·9	26·7	6·5	23·8	20·2	5·9	9·3	3·3	3·4	6·0	1073	2273	1286	1200	987
6. Calcareous Rice Soils (one soil)	9·5	37	13·5	27·5	23·5	·0	7	6	7	1	0·4	4·8	2·0	4·4	2·8	6·0	6·9	3·0	0·9	3·9	1877	3867	1547	1990	2320
7. Non-lateritic Clayey Rice Soils ..	14	36	11	22	25	·5	91	23	86	68	18·5	28·8	2·2	10·3	26·6	7·5	9·3	3·5	1·8	5·8	2078	3271	1278	1193	1993

TABLE V—West Soils

	Initial NH_4 ppm N	Max. NH_4 ppm N	Final NH_4 ppm N	Diff. initial & max NH_4 ppm N	Diff. max. & final NH_4 ppm N	Initial Fe ppm	Max. Fe ppm	Final Fe ppm	Diff. initial & max. Fe ppm	Diff. Max. & final Fe ppm	Initial Mn ppm	Max. Mn ppm	Final Mn ppm	Diff. initial & max. Mn ppm	Diff. max. & final Mn ppm	Initial oxy : M	Max. oxy. M	Final oxy. M	Diff. initial & max. oxy. M	Diff. max. & final oxy M	pH initial	pH final	pH diff. initial & final
(1) *Strongly Acid lateritic Rice Soils of the Ultra Wet Zone*																							
1. Panagoda	195	246	83	51	163	208	1182	860	974	322	3·0	3·8	1·3	·8	2·5	3·0	9·3	3·7	6·3	5·6	4·86	6·30	1·44
2. Mirigama	26	229	110	203	119	107	3006	2440	2899	566	142	162	128	20	34	9·5	9·8	5·6	7·3	4·2	4·65	6·45	1·80
3. Mapalana	29	200	46	171	154	408	2728	2005	2320	723	20	20	12·3	0	7·7	8·4	8·6	6·1	6·2	2·5	4·70	6·60	1·90
4. Karapincha ..	48	183	100	135	83	219	1968	1401	1749	567	18	19·7	15·1	1·7	4·6	1·4	11·2	5·3	9·8	5·9	5·14	6·80	1·66
(2) *Strongly Acid Humic Rice Soils*																							
1. Bombuwela Peaty ..	57	263	187	206	76	328	3042	2250	2714	792	6	6	1·7	0	4·3	2·1	10·9	8·6	8·8	2·3	4·65	6·45	1·80
(3) *Ground Water Podzolic Rice Soils*																							
1. Bombuwela Sandy ..	20	197	60	177	137	75	237	170	162	67	5	5	2·1	0	2·9	1·8	4·8	1·3	3·0	3·5	5·62	6·90	1·28
2. Batticaloa ..	16	196	53	180	143	48	194	120	146	74	9	9	3·9	0	5·1	2·0	2·4	1·2	0·4	1·2	532	7·00	1·68
(4) *Acid lateritic Rice Soils of the Wet Zone*																							
1. Welimada	34	208	106	174	102	85	5883	3534	5798	2349	247	346	235	99	111	1·3	12·5	9·3	11·2	3·2	5·30	6·90	1·60
2. Bibile	147	159	85	12	74	77	2164	1730	2087	434	190	237	170	47	67	1·3	7·6	3·7	6·3	3·9	5·65	7·00	1·35
3. Peradeniya ..	121	355	124	234	231	239	6596	3343	6357	3253	408	429	295	21	134	3·7	14·8	9·0	11·1	5·8	5·55	6·85	1·30
4. Kundasale ..	20	105	76	85	29	343	4545	2580	4202	1965	233	296	187	63	109	1·8	8·8	5·8	7·0	3·0	6·60	7·05	0·45
5. Matale	27	342	99	315	243	240	7358	4703	7118	2655	199	246	151	47	95	2·5	10·9	10·6	8·4	0·3	5·38	7·00	1·62
6. Nalanda	46	257	120	211	137	64	3014	2595	2950	419	165	222	180	57	42	2·3	6·8	5·5	4·5	1·3	5·41	7·00	1·59
(5) *Non-lateritic Rice Soils of the Dry Zone*																							
1. Polonnaruwa ..	36	263	115	227	148	381	2284	1762	1903	522	478	557	429	79	128	2·0	6·0	5·5	4·0	0·5	7·30	7·30	0
2. Hingurakgoda ..	29	305	84	276	221	102	1284	1212	1182	72	136	146	98	10	48	2·8	5·5	4·2	2·7	1·3	7·47	7·32	–·15
3. Maha Illuppalama Grey ..	12	264	96	252	168	12	1930	1669	1918	261	149	294	205	145	89	1·9	5·1	3·8	3·2	1·3	7·39	7·30	–·09
4. Maha Illuppallama Red ..	25	237	119	212	118	10	2251	2097	2241	154	269	522	395	253	127	2·0	5·9	4·8	3·9	1·1	6 88	7·20	0·32
(6) *Calcareous Rice Soils*																							
1. Jaffna	40	173	93	133	80	9	930	802	921	128	84	114	98	30	16	0·9	3·2	2·8	2·3	0·4	6·90	7·65	0·75
(7) *Non-lateritic Clayey Rice Soils*																							
1. Ambalantota 1 ..	47	253	160	206	93	379	5533	3911	5154	1622	360	470	407	110	63	3·6	11·7	8·1	8·1	3·6	6·43	7·20	0·77
2. Ambalantota 2 ..	34	284	184	250	100	74	5027	3750	4953	1277	320	439	384	119	55	2·1	11·4	8·4	9·3	3·0	6·42	7·00	0·58

Table VI—West Soils Averages

	Initial NH_4 ppm N	Maximum NH_4 ppm N	Final NH_4 ppm N	Diff: initial & max: ppm N	Diff: max: & final ppm N	Initial Fe ppm	Max: Fe ppm	Final Fe ppm	Diff: initial & max: Fe ppm	Diff: max: & final Fe ppm	Initial Mn ppm	Maximum Mn ppm	Final Mn ppm	Diff: initial & maximum Mn ppm	Diff: Maximum & final Mn ppm	Initial oxy: matter	Maximum oxy: matter	Final oxy: matter	Difference initial & maximum oxy: matter	Difference maximum & final oxy: matter	pH initial	pH final	pH difference initial & final
1. Strongly Acid lateritic Rice Soils of the Ultra Wet Zone	75	212	85	137	127	236	2157	1677	1921	480	46	48	39	2	9	2·3	8·8	5·2	6·5	3·6	4·9	6·6	1·7
2. Strongly Acid Humic Rice Soils (one soil) ..	57	263	187	206	76	328	3042	2250	2714	792	6	6	1·7	0	4·3	2·1	10·5	8·6	8·4	1·9	4·6	6·5	1·9
3. Ground Water Podzolic Rice Soils ..	18	197	57	179	140	62	210	145	148	65	7	7	3	0	4	1·9	3·5	1·3	1·6	2·2	5·7	7·0	1·3
4. Acid lateritic Rice soils of the Wet Zone ..	66	216	102	150	114	175	4885	3081	4710	1804	240	289	203	49	86	2·1	9·5	7·3	7·4	2·2	5·7	7·0	1·3
4. Non lateritic Rice Soils of the Dry Zone ..	26	259	104	233	155	126	1825	1685	1699	140	258	363	282	105	81	2·2	5·3	4·6	3·1	·07	6·6	7·3	0·7
6. Calcareous Rice Soils (one soil)	40	173	93	133	80	9	930	802	921	128	84	114	98	30	16	0·9	3·2	2·8	2·3	0·4	6·9	7·7	0·8
7. Non lateritic Clayey Rice Soils	41	268	172	227	96	227	5162	3331	4935	1331	340	455	396	115	59	2·9	11·1	8·3	8·2	2·8	6·4	7·1	0·7

METEOROLOGICAL REPORT

Summary for October to December, 1961

SOUTH-WEST monsoon weather continued for some time in October too, giving light to moderate rain in the south-west quarter with occasional, scattered evening thundershowers in the Northern and Eastern Provinces. With the weakening of the westerly current about the 10th, intermonsoonal conditions began to set in. Between the 14th and 16th however, unsettled conditions, caused by a low pressure area, resulted in intermittent rain in the south-west quarter and thundershowers over the Central, North-Central and Eastern Provinces. Intermonsoon conditions were well established by the 18th, after which afternoon and evening thundershowers were fairly widespread over the Island. An unusual phenomenon which attracted public attention towards the end of the month was the occurrence of thin haze over several parts of Ceylon for a few days from the 25th, particularly during the mornings and the afternoons. It is probable that this originated from some local cause, such as smoke from chimneys or jungle fire and persisted owing to lack of wind and convection. A Hailstorm was reported from Gurutalawa about twelve noon on the 18th. The greater monthly totals of rainfall (of the order of 25 inches) occurred in the Kalutara, Ratnapura and Kegalla Districts. Southwestern coastal areas received monthly aggregates of the order of 15 inches, while outside the south-west quarter the totals were generally below 10 inches. Least rain (totals below 2 inches) occurred scattered in places along the eastern coast. Rainfall was above normal in the western and south-western low-country, while elsewhere in the Island it did not deviate appreciably from average. There were about 18 daily falls over 5 inches, 7.55 inches at Ronorawa on the 31st being the greatest.

Intermonsoon conditions were well in evidence throughout November, with generally widespread thundershowers during the afternoon and evening. Thunder was severe at times and has been responsible for a few deaths. Owing to a low pressure area the weather conditions became unsettled on the 19th, and heavy, widespread rain was experienced in the eastern parts of the Island, rainfall at a number of stations in Gal Oya Valley and on the eastern slopes of the central hills exceeding 5 inches. The resulting floods caused much damage to paddy crops in Gal Oya Valley and Akkaraipattu

areas. A Hailstorm was reported from Dekatana (Dompe) during the afternoon of the 18th. The greater monthly total of rainfall (of the order of 30 inches) occurred on the north-eastern slopes of the central hills, in the Bibile-Amparai area and at places along the eastern coast. In the western low country, south-east quarter and in northern and eastern parts the monthly aggregates were generally of the order of 15 inches, while elsewhere the totals were mainly between 5 and 10 inches. The rainfall was above normal over most of the eastern half of the Island and generally below normal elsewhere. There were about 60 daily falls over 5 inches, the highest being 11.60 inches at Irakkamam on the 19th.

During the first few days of December the weather over the Island became unsettled due to a low pressure area to the East of Ceylon, and fairly widespread rainfall was experienced. This rain was considerably heavy on the 2nd, particularly in the North-central and Eastern Provinces and on the north-eastern slopes of the central hills, where many stations recorded falls exceeding 5 inches. These rains resulted in floods in the low-lying areas of the Eastern Province. The north-east monsoon was established by the 6th and there was monsoon rain in the east and north-east and over the Central Province with scattered evening thundershowers in the south-west quarter. These conditions continued till the 16th, after which generally fair weather prevailed over most of the Island up to the 27th due to dry upper air streams. Fairly widespread rain was again experienced from the 29th onwards. The greater monthly totals of rainfall were of the order of 35 inches and occurred on the north-eastern slopes of the central hills. Elsewhere over the Island the rainfall ranged generally between 5 and 25 inches. Least rainfall (below 5 inches) was confined to parts of the north-western province and to the coastal belt of the southern province. The rainfall was above normal over practically the entire eastern half of the Island, in the Colombo and Kalutara Districts and in the southern portions of the Kegalle and Kandy Districts. Elsewhere the rainfall was below normal. There were over 50 daily falls exceeding 5 inches, the highest being 10.17 inches at Batticaloa on the 2nd.

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METEOROLOGICAL REPORT FOR OCTOBER TO DECEMBER, 1961

OCTOBER

Station	Temperature				Humidity			Rainfall			
	Mean Max	Offset	Mean Min	Offset	Day	Night (from Min)	Amount of Cloud	Amount	Offset	Rain Days	Offset
	°		°		%	%			Inches		
Anuradhapura	92·6	+3·7	73·9	+0·4	64	90	5·1	10·22	+0·50	15	—1
Badulla ..	83·7	+0·9	65·1	—0·4	71	95	5·6	7·89	—1·00	17	—2
Batticaloa ..	87·8	+0·8	75·1	—0·2	73	91	4·6	1·69	—5·50	7	—6
Colombo ..	85·3	+0·5	74·2	—0·6	81	90	6·2	19·07	+5·36	25	+2
Diyatalawa ..	75·8	—0·5	60·2	—0·3	77	91	6·3	10·01	+0·83	23	+3
Galle ..	82·6	—0·3	74·2	—1·2	80	88	5·8	17·98	+5·93	28	+8
Hambantota ..	83·3	—2·9	74·7	—0·6	82	88	6·6	14·27	+9·51	18	+5
Jaffna ..	86·7	+1·0	78·2	+0·6	82	89	5·6	2·90	—6·30	9	—3
Kandy ..	83·4	—1·8	68·0	+0·1	70	90	6·1	10·94	—0·67	18	0
Kankesanturai	87·9	+1·0	77·0	—0·1	76	91	5·0	5·05	—4·57	8	—3
Kurunegala ..	88·3	+1·2	73·5	+0·3	73	93	5·8	13·04	—1·82	19	—1
M'Illuppallama	91·9	+3·8	73·6	+0·3	61	86	5·6	12·12	+2·66	15	0
Mannar ..	88·9	+2·1	77·7	+0·3	76	89	5·6	1·94	—4·64	9	—2
Nuwara Eliya ..	67·9	+0·3	52·9	+0·7	84	91	6·2	6·41	—3·35	19	—3
Puttalam ..	88·3	+2·0	76·0	+0·4	66	82	5·4	8·68	+1·25	12	—2
Ratmalana ..	85·7	+0·6	75·0	+0·1	73	88	6·2	17·40	+4·20	24	—
Ratnapura ..	88·0	+0·9	72·3	—0·5	70	85	6·5	16·00	—2·01	24	+1
Talawakele ..	—	—	—	—	—	—	—	—	—	—	—
Trincomalee ..	90·0	+2·0	75·9	+0·3	70	86	5·1	4·91	—4·64	12	—4
Mullaitivu ..	90·7	—	73·6	—	69	90	4·6	3·45	—8·11	12	—
Katunayake ..	85·7	—	74·1	—	79	93	6·0	9·20	—	24	—
Vavuniya ..	92·9	—	73·3	—	63	90	5·4	6·04	—2·76	16	—

NOVEMBER

Station	Temperature				Humidity			Rainfall			
	Mean Max	Offset	Mean Min	Offset	Day	Night (from Min)	Amount of Cloud	Amount	Offset	Rain Days	Offset
	°		°		%	%			Inches		
Anuradhapua	85·6	—0·2	72·7	+1·3	80	95	2·7	8·38	—2·29	21	+2
Badulla ..	77·9	—1·4	66·1	+0·7	84	95	6·4	13·14	+2·89	25	+3
Batticaloa ..	83·7	—0·5	74·8	+0·6	82	93	5·8	23·28	+9·42	24	+6
Colombo ..	85·9	+0·7	72·9	—0·4	80	90	6·3	19·83	+6·74	23	+3
Diyatalawa ..	73·2	—1·1	60·6	+0·8	86	97	6·8	7·58	—2·84	23	+1
Galle ..	84·9	+1·3	73·8	—0·4	78	90	5·4	7·23	—4·78	21	+2
Hambantota ..	84·2	—1·2	74·3	+0·3	80	90	5·6	8·15	+0·58	20	+4
Jaffna ..	84·9	+0·8	75·2	+0·4	79	91	6·1	15·12	—2·15	21	+3
Kandy ..	82·6	—0·3	68·3	+0·9	73	87	6·4	10·62	—0·08	22	+4
Kankesanturai	84·6	+0·4	75·6	+0·2	81	88	6·2	16·66	—0·48	21	+6
Kurunegala ..	86·8	+0·1	72·3	+0·5	74	93	6·4	9·95	—2·44	15	—4
M'Illuppallama	85·4	—0·2	72·0	+1·5	74	88	6·4	10·28	+0·32	23	+7
Mannar ..	84·7	—0·1	75·8	+0·1	83	93	6·4	9·33	—0·86	19	+2
Nuwara Eliya ..	67·0	—0·8	53·5	+2·4	88	94	6·7	10·15	+0·96	26	+4
Puttalam ..	86·7	+1·0	73·4	+0·3	72	86	6·2	7·40	—2·73	22	+4
Ratmalana ..	86·7	+0·3	73·6	+0·7	71	88	6·2	10·77	—1·35	21	—
Ratnapura ..	89·2	+1·4	72·2	0	70	83	6·8	15·00	+0·21	24	+2
Talawakele ..	—	—	—	—	—	—	—	—	—	—	—
Trincomalee ..	84·0	+0·4	76·4	+1·6	80	86	6·4	22·19	+8·25	23	+4
Mullaitivu ..	85·0	—	76·0	—	79	84	5·3	14·05	—2·00	22	—
Katunayake ..	87·3	—	72·8	—	75	93	5·7	15·01	—	19	—
Vavuniya ..	85·0	—	71·9	—	78	78	6·2	13·54	+0·49	20	—

Station	DECEMBER										
	Temperature				Humidity			Rainfall			
	Mean Max	Offset	Mean Min	Offset	Day	Night (from Min)	Amo-unut of Cloud	Amo-unt	Offset	Rain Days	Offset
	°		°		%	%			Inches		
Anuradhapura	82·6	—0·7	70·8	+0·8	81	95	5·5	8·82	+1·30	16	0
Badulla ..	76·3	—0·3	65·0	+0·5	83	94	6·7	12·00	+0·77	22	+1
Batticaloa ..	82·0	+0·1	74·3	+0·7	81	90	6·5	27·67	+10·68	26	+6
Colombo ..	86·3	+0·8	72·1	—0·2	78	90	5·6	10·25	+4·64	14	+2
Diyatalawa ..	71·6	—0·4	58·9	+0·3	85	97	7·1	7·52	—0·55	19	—1
Galle ..	85·0	+1·5	73·3	0	75	88	6·0	4·09	—3·73	12	—2
Hambantota ..	85·2	+0·5	73·4	+0·3	74	88	5·6	5·25	—0·36	9	—4
Jaffna ..	82·5	0	73·3	+0·3	79	93	5·5	6·53	—3·86	14	0
Kandy ..	81·9	+0·1	66·6	+0·8	70	87	5·8	8·92	+0·05	13	0
Kankesanturai	82·4	—0·3	74·8	—0·1	80	86	5·2	10·60	+0·86	16	+4
Kurunegala ..	85·5	—0·2	70·6	—0·1	72	93	5·5	4·10	—2·68	10	—3
M'Illuppallama	83·0	+0·4	69·8	+0·2	76	87	6·0	10·42	+2·36	15	+2
Mannar ..	82·3	—0·5	74·8	—0·1	85	93	5·8	5·50	—2·29	16	+2
Nuwara Eliya	67·6	—0·1	50·4	+1·4	85	93	5·8	7·20	—0·61	16	—1
Puttalam ..	85·2	+0·4	71·0	—0·2	70	88	5·8	4·50	—1·05	14	+1
Ratmalana ..	87·4	+1·0	72·5	+0·8	67	85	5·7	9·97	+3·32	14	—
Ratnapura ..	89·9	+1·8	71·4	—0·2	65	83	6·4	6·35	—2·77	16	0
Talawakele ..	—	—	—	—	—	—	—	—	—	—	—
Trincomalee ..	81·8	+0·7	75·7	+0·8	81	84	6·4	21·64	+8·64	21	+3
Mullaitivu ..	82·5	—	75·5	—	79	82	5·5	13·63	+0·11	14	—
Katunayake ..	88·1	—	71·8	—	69	74	5·1	3·99	—	13	—
Vauniya ..	82·4	—	70·1	—	78	93	5·6	16·10	+4·52	19	—